41e

J C Branner

SOCIETY FOR THE ENCOURAGEMENT OF
ARTS, MANUFACTURES & COMMERCE.

# Cantor Lectures

ON

# GOLD MINING AND GOLD PRODUCTION.

BY

PROF. JOHN WALTER GREGORY,
D.Sc., F.R.S., F.G.S.



*Delivered before the Society of Arts on January 28, and February 4, 11, 1907.*

LONDON:
PRINTED BY WILLIAM TROUNCE, 10, GOUGH SQUARE, FLEET STREET, E.C.

1907.

*Price One Shilling.*

SOCIETY FOR THE ENCOURAGEMENT OF ARTS, MANUFACTURES & COMMERCE.

# Cantor Lectures

ON

# GOLD MINING AND GOLD PRODUCTION.

BY

PROF. JOHN WALTER GREGORY,
D.Sc., F.R.S., F.G.S.

*Delivered before the Society of Arts on January 28, and February 4, 11, 1907.*

LONDON:
PRINTED BY WILLIAM TROUNCE, 10, GOUGH SQUARE, FLEET STREET, E.C.
1907.

# SYLLABUS.

---

### Lecture I.

*Alluvial Gold Mining.*—Small scale methods and manual appliances—Hydraulic sluicing—Gold dredges; chief types; ground to which suitable; costs—The deep leads of Australia; their nature; distribution; methods of discovery and mining.

### Lecture II.

*Lode Mining.*—The term "reef" used both for ore and "country" rock—The chief types of gold-bearing lodes—The importance of ore genesis in reference to mine development—The chief gold fields of the world and their structures—The Rand and its banket.

### Lecture III.

*Gold Production.*—The crushing of the ore; the stamp mill—The extraction of gold by amalgamation; smelting; chlorination and cyanidation—Reforms in consequence of the tube mill and the filter press—The depth of ores; surface and secondary enrichment—Mining costs and gold mining organisation.

# INDEX.

LECTURE I.—ALLUVIAL GOLD MINING.


| | Page. |
|---|---|
| The Source of Gold | 5 |
| Alluvial Gold | 6 |
| Gold Washing and Sluicing | 6 |
| Gold Dredging | 8 |
| Deep Leads | 11 |
| Scope of Alluvial Mining and Choice of Method | 15 |


LECTURE II.—GOLD-BEARING LODES.


| | Page. |
|---|---|
| The term Reef and its opposite meanings | 16 |
| Classification of Gold-Bearing Lodes | 16 |
| 1. Gold-Quartz Lodes in Sedimentary Rocks | 17 |
| 2. Gold-Quartz Lodes in Foliated Igneous Rocks | 18 |
| 3. Mineralised Gold-Bearing Belts | 19 |
| 4. Lodes connected with Propylitic Diorites | 20 |
| 5. Gold Lodes in normal Volcanic Rocks | 21 |
| 6. Gold in Sulphide Ore Masses | 22 |
| 7. Gold Impregnations in Sedimentary Rocks | 22 |
| 8. Banket | 22 |
| The Microscope in Mining Geology | 23 |
| Practical Value of Determination of Ore Genesis | 23 |


LECTURE III.—GOLD EXTRACTION, THE VARIATIONS OF GOLD MINES IN DEPTH, AND THE GOLD MINING INDUSTRY.


| | Page. |
|---|---|
| The Stamp Battery | 26 |
| Gold Extraction | 28 |
| ,, ,, —The Cyanide Process | 29 |
| Fine Crushing—the Tube Mill and Filter Press | 30 |
| Do. Suggested Abolition of the Battery | 31 |
| Gold Yield of 1906 | 32 |
| Variations of Gold Mines in Depth | 32 |
| Do. Secondary Enrichment | 32 |
| Mining Costs | 33 |
| Gold Mining as an Industry | 34 |

# GOLD MINING AND GOLD PRODUCTION.

*LECTURE I.—DELIVERED JANUARY 28, 1907.*

## I.—ALLUVIAL GOLD MINES.

Mining is the art of obtaining minerals and ores from the earth, and the best mining is that which does its work at the minimum of cost and with the maximum of profit. The gold miner uses many of the methods employed in mining for commoner materials, but he adapts them to suit his particular difficulties, and adopts many special contrivances of his own. The distribution of gold in nature is governed by its special properties, and they also determine the methods by which it can be sought and won. Thus, the reluctance of gold to enter into combination renders even the smallest grains of it almost indestructible, for they neither rust nor dissolve appreciably in any common solvent. The brilliant colour, which gives gold its decorative value, causes minute specks of it to be readily visible. Its unequalled malleability enables grains to be hammered out into broad flakes, which are conspicuous out of all proportion to their bulk. The relative scarcity of gold, which makes it a suitable standard of value, leads men to mine it in the remotest and most inaccessible corners of the globe, and enables them sometimes to earn a profit by extracting it from deposits, which contain only one part of gold in over 200 million parts by volume of earth. This remarkable feat is possible only owing to the exceptional heaviness of gold, which causes its natural concentration on river beds and allows its easy collection in miners' sluices.

### THE SOURCE OF GOLD.

All the gold that is accessible to us must have come from one of two sources—the sea or the igneous rocks of the earth's crust. Sea water contains a small trace of gold; and if the vast volume of sea water has in solution even a very minute proportion of the metal, the oceans must hold a quantity which, if it could all be extracted, would render gold a drug upon the market. The prospects of extracting gold from sea water as a commercial process are not hopeful. Liversidge estimates the amount at about a grain of gold to the ton of sea water, but, according to Don, the sea contains only ·07 grain per ton, or about 1-100th of the amount which the waste waters of many cyanide plants are allowed to carry away in solution.

So far from the sea being the primary source of gold, there is no well-established case in which the gold found in the rocks has been deposited in them by precipitation from the sea. Whatever gold there may be in sea water has probably been obtained by the solution of gold grains upon the shore, and it is, therefore, secondary and not primary in origin.

Hence we are driven to seek the original source of gold in the only alternative—the interior of the earth. The one fact certainly known about the interior of our earth is that it is much heavier than the rocks which compose its outer crust or shell. This view was advanced as an hypothesis by Isaac Newton, and it was demonstrated in 1774, when Maskelyne, using Mount Schiehallion, in Perthshire, as his weight, and a plumb line as his balance, actually weighed the whole earth. He found that its density is nearly twice as great as that of the rocks which form its crust; and later measurements have proved that the internal mass of the earth is even heavier than Maskelyne thought. The central mass of the earth is so heavy that Posepny appropriately named it the "barysphere," or heavy sphere. The simplest explanation of the great weight of the barysphere is that it is loaded with heavy metals; and, according to the calculations by Hutton, in 1779, based on Maskelyne's observations, the heavy "metalline part," as Hutton called it, must occupy $\frac{20}{31}$, or nearly two-thirds of the diameter of the earth. Direct evidence in support of the concentration of metals in the interior is supplied by the fact that the primary ores of gold occur either in those old rocks which have once been deepest below the

surface, or in localities connected with the interior by fractures in the crust or by volcanic action. Alluvial gold may be found in rocks of any age, from Archean times to deposits that are still forming. But the majority of the gold-bearing lodes of the world, as in Russia, India, South Africa, Brazil, and many of the gold-fields of North America and Australia, occur in very ancient rocks that have been at one time deeply buried beneath the surface, or were formed nearer the earth's barysphere than later deposits.

The gold found in veins in the younger rocks occurs chiefly along great fractures through the crust, as in the Sierra Nevada of California, or else in association with igneous rocks that have been forced up from below, such as the volcanic neck of Cripple Creek, in Colorado, and the intrusive igneous rocks of the Thames Goldfield, in New Zealand. In both cases the gold in the younger veins has, doubtless, been brought up from below by vapours or solutions escaping from the deep, intensely-heated barysphere.

## Alluvial Gold.

Gold ores may be divided into two groups—primary ores, wherein the gold has been introduced in solution, such as veins, lodes, or masses; and secondary ores, into which the gold has been carried in fragments, derived from primary ores by the mechanical action of wind or water. (Fig. 1). Alluvial gold is derived from the destruction of primary gold-bearing deposits. The light, earthy material in the lodes is swept away by wind or stream; but gold, being nearly eight times as heavy as its usual companion, quartz (the specific gravity of gold being 19·33 and that of quartz 2·6), does not travel far. It comes to rest all the sooner owing to its softness, for the angular grains are worn into rounded pellets, and the flakes are rolled into cylinders, which from their size and shape are often called "mouse droppings;" and the gold, therefore, offers little surface to the water.

Fig. 1.

The Kum Tow Gold Nugget, from the Rheola Goldfield in North-Western Victoria. From a photograph issued by the Mines Department, Victoria. The nugget was discovered on April 17, 1871, at the depth of 12½ feet. Gross weight, 795 oz. 19 dwt.; value £2,872.

In arid regions, or in positions where the decomposed lodes are exposed only to the action of wind and occasional rain, the gold remains in rough particles, close beside the lode from which it fell. It is known as "shed gold," and may be recognised by the angularity and raggedness of the grains. Where, on the other hand, the gold is carried along by a stream, it is rolled into the rounded forms characteristic of water-worn gold.

## Gold Washing and Sluicing.

The first stage in the history of a gold-field is generally the discovery of its alluvial gold. There is a "rush" to the locality; the miners peg out their claims, according to the regu-

lations of the local law, and they dig shallow pits into the gravel or coarse sand, in which alluvial gold generally occurs.

The simplest method of extracting the gold is to wash the "dirt," as it is called, in a tin dish or pan. An ordinary tin dish when well heaped up holds 20 or 25 pounds of earth, and there are usually about from 150 to 180 dishfulls to the cubic yard. The material is stirred with water, the washed pebbles are picked out by hand, and by a swirling motion of the water the earth is washed away and the heavy metallic particles left in the dish. The gold is in the form of grains and thin specks known as "colors;" on the average about 35 colors weigh one grain. If the gold collected from one dishfull weighs one grain the material is worth about four dwt. to the ton, or six dwt. to the cubic yard.

The tin dish is only serviceable in prospecting, in working small pockets of very rich ore, or in extracting gold which has been concentrated by some other process, such as sweeping the surface of the bed rock exposed by the removal of the overlying gold-bearing gravels.

Poorer ores must be handled in larger quantities, in some such machine as the miner's cradle. It is a box about three or four feet long, one and a half or two feet wide and deep. The top of the box consists of a sieve into which the earth is shovelled, water is poured on to the earth from a can, and the material is washed by swinging the machine to and fro on its rockers. The fine material falls through the sieve on to a sloping piece of wood covered with plush, on the rough hairy surface of which the gold is collected, while the lighter mud and sand are swept away by the current. This machine, a Californian invention, is very efficient in the recovery of fine gold. Poorer material may be treated by being washed by a stream of water down a long trough or sluice-box, of which the modern form is popularly known as a "long tom." The long tom consists of a trough, usually about 12 feet long and 20 inches wide, with a slope of about one inch in a foot; the floor of the lower part of this trough is crossed by a series of ridges which catch the gold.

The long tom is suited to the requirements of a small party of working miners; for operations on a larger scale the same method is used, but there is a longer "sluice." It consists of a very long trough or channel, composed of a series of wooden sluice boxes, like the long tom, or of a trench cut in a rock, or of both. Thus the Colombian Hydraulic Company used a sluice composed of 2,839 feet of boxes and 502 feet of trench cut in rock. Such long sluices requires hundreds of sluice boxes, placed end to end, till they are sometimes about a mile in length. The usual gradient is a fall of about 1 in 24.

If the gold-bearing material is so compact that it does not readily fall to pieces in water, then it has to be crushed before it can be washed; it may be broken by being pounded in a tub of water with a dolly; or it may be broken up on a larger scale in a puddling machine, in which the power is supplied by a horse, water-power, or steam. This process of puddling may be used where water is so scarce that it cannot be allowed to run freely away as in sluicing.

In these various contrivances the essential procedure is the same. The material is stirred up with water, which washes away the light earth, while the heavy gold is caught on the floor against ridges of wood or angle iron, known as "riffles," or upon rough surfaces such as blankets, or by means of mercury, with which gold readily combines as an amalgam.

The grade of ore which can be worked by these devices depends upon the scale on which the material can be handled. The greatest achievement in mining on these lines is the system of hydraulic sluicing, which we owe to California. The gold-bearing gravels occur there on the flanks of the Sierra Nevada, so water can be impounded in reservoirs at a higher level and brought to the mine by a ditch or race. The water falls down a steel or iron pipe (coated inside with asphalte to prevent it rusting) to the level of the gold-bearing deposits, against which it is directed by a huge nozzle, usually called a "Giant." The water leaps from the nozzle and falls with such force on the cliff that it tears away the materials like a steam navvy. For example, at Fresno, in California, the pipe line from the open race to the nozzle was 4,020 feet long, and had a fall of 1,411 feet. The weight of the column of water was 317 tons, so the pipe increased in thickness from $\frac{1}{4}$ inch steel at the top to $\frac{5}{8}$ inch steel at the bottom. The water was discharged through a nozzle $1\frac{1}{2}$ inch in diameter, with a thrust of 93 tons, at a speed of 100 miles per hour.

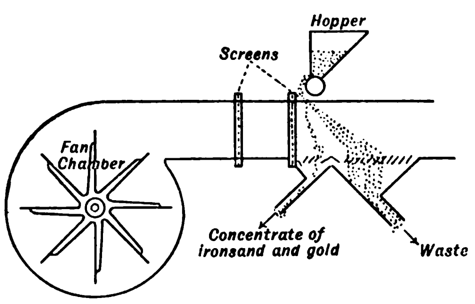
Such a powerful jet digs into the base of the cliff and undermines it; the gravel falls in huge masses which are broken up by the play of water, and the loose material is swept

away down the sluice. Large stones, fifteen pounds in weight, are carried along like corks, while the heavy grains of gold rest against ridges, or are caught by mercury in depressions on the floor of the sluice.

This system of mining is cheap where abundant water-power is available. The water may have to be collected in some distant valley and brought to the mine by a long and costly aqueduct. But where water and a good fall are locally available the equipment is inexpensive, the power costs practically nothing, and little labour is required. In such cases hydraulic mining has been profitably employed upon deposits, which yield only one part of gold in every sixteen million parts by weight of earth.

Modifications in the system of hydraulic sluicing are required under different geographical conditions. Thus in the famous Arctic goldfield of the Klondyke the ground, being permanently frozen, has to be thawed by fires before the gravels can be disintegrated and washed. A very different method of

FIG. 2.




THE EDISON DRY CONCENTRATOR (after Chapman).

alluvial mining is necessary in arid tropical regions. Hydraulic mining is impossible on the plains of Westralia, where water has often cost one shilling or even two shillings a gallon, and was far too expensive a luxury to use in gold washing. Hence the Westralian miners developed the system of dry blowing; gold-bearing earth is crumbled to powder and allowed to fall in a stream before a pair of bellows, which blows the light sand and clay aside, while the heavy gold falls vertically on to a tray. Edison's dry concentrator (Fig. 2) is a more elaborate machine of the same type. It is used, *e.g.*, in the Golden Mountain of New Mexico; the blast is produced by a powerful fan, and acts on the sand, falling across a tube; the sand is blown along the tube while the gold and black iron-sand fall into a separate hopper. The concentrate is then allowed to fall like solid rain before some powerful electric magnets; they attract the black iron sand and the dry separation of the gold is thus completed magnetically.

In other gold fields, sluicing is prevented by the presence of too much water. River beds are often auriferous; and the simplest method of obtaining this material is to build a wing dam, forming a dock in the river; the dock can be emptied by a Californian pump, driven by the river current, and the material on the bed then mined and treated.

A second method is to divert the river from its course by cutting a canal or tunnel through a spur of land, and thus draining a whole reach or meander of the river. This work may be expensive; but it leaves bare a considerable area of river bed. This method is at least as old as Job, who tells us that the miner bindeth the rivers that they flow not. One of the best known modern cases was the binding of the Feather River, in California, so that it no longer flowed through the loop of its channel occupied by the Cape Claim, near Oroville; the miners recovered £120,000 of gold before the river suddenly retook possession of its bed.

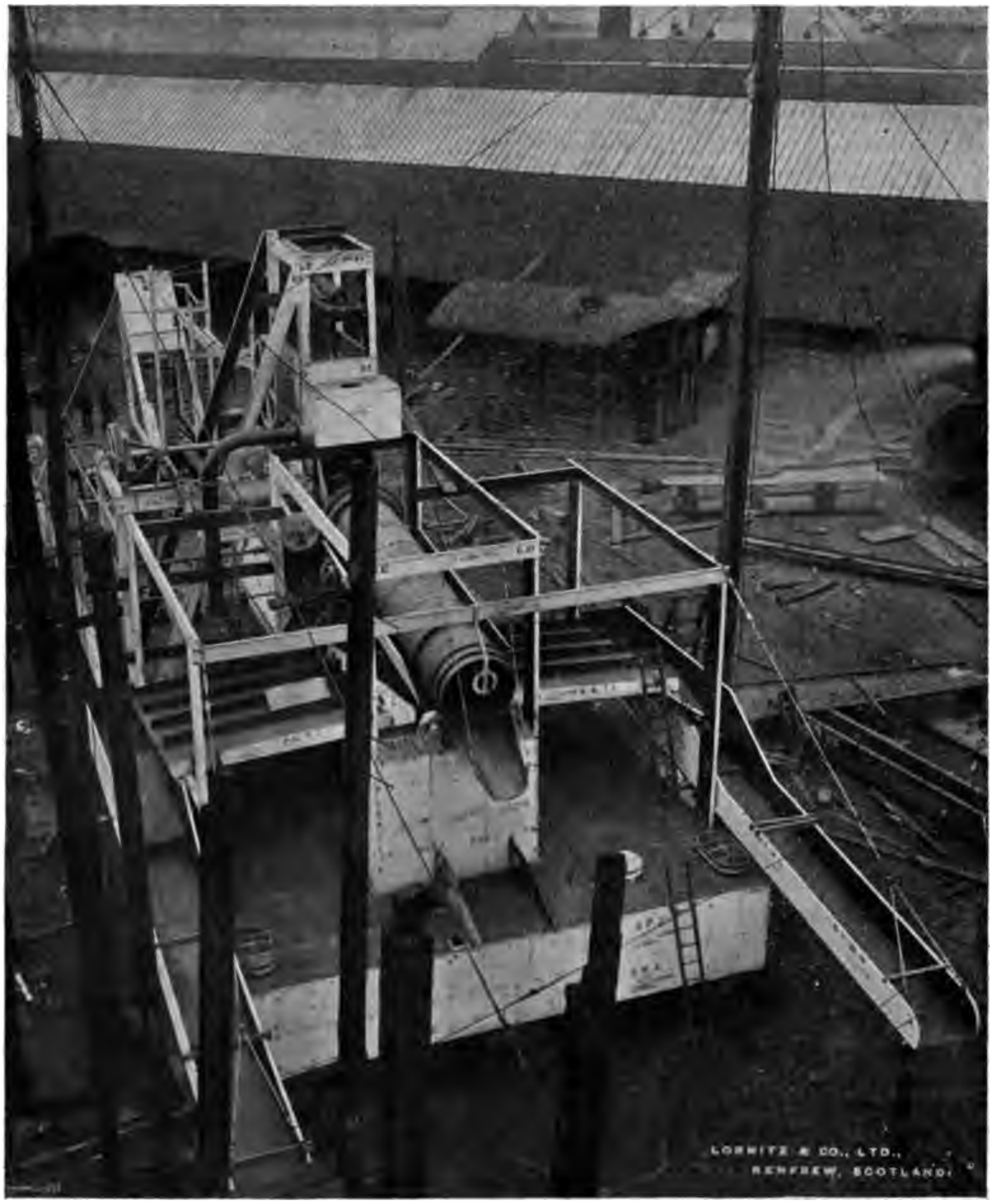
## GOLD DREDGING.

During the past twenty years, a new and still more effective method of working gold-bearing river beds has been developed owing to the inventive ingenuity of the miners in the Dominion of New Zealand. Many of the rivers in the South Island of New Zealand could not be conveniently diverted or worked by wing-dams; so the miners scooped up the gravels beneath these rivers in a small trawl or "spoon dredge," consisting of a leather bag, armed with a steel rim or lip. It was fastened to a pole, and dragged over the river bed. In 1881 it occurred to Mr. McQueen, of Dunedin, "the father of gold-dredging," that the bucket-dredge, well known from its use in deepening rivers and harbours, might be used to replace this crude contrivance. The "Dunedin Gold Steam-Dredging Company, Limited," was founded, a dredge built, and successfully employed, in 1882, on the Clutha River, in New Zealand. Its success marks the real foundation of the great industry of gold dredging.

The simplest, and as a rule the most economical type of dredge, consists of a barge, from which a chain of buckets on a continuous jointed ladder is forced against the river bed, by being hauled round the end of a boom; the

buckets dig up the gravel, lift it above the deck and discharge it on to a sloping platform of bars—a grizzly. The grizzly separates the bars of the grizzly into a cylindrical revolving screen, known from its shape, as a " trommel," the German word for a drum. The pebbles

FIG. 4.




PART OF THE SEPARATING AND GOLD SAVING APPARATUS OF A DREDGE. (From a photograph lent by Messrs. Lobnitz and Co.).—**The trommel is seen in the centre, and the gold saving tables project forward on each side of the front of the photograph.**

arge boulders which slide down it on to the deck of the dredge, or fall into a boat, from which they can be dumped safely out of the way. The finer material passes between the run in a stream down the inside of the screen; while the fine material falls through the holes on to the washing tables; the fine clay floats away in the water; the sand is washed down

the sluice boxes, where the gold is caught against obstacles, or in the hairs of the baize, coco-nut matting, plush or blankets on the floor of the boxes. The barren waste material or "tailings" were at first dropped over the stern of the dredge, whence it soon worked forward and was redredged. The re-working of the material was such a ruinous waste of power, that the river could only be dredged in patches; but after several attempts a successful tailings elevator was invented in New Zealand in 1894, and after that date the dredging industry made rapid progress. The usual forms of tailings elevator consists either of a chain of

FIG. 3.

A GOLD-DREDGE (from a photograph lent by Messrs. Lobnitz & Co., Renfrew). The chain of buckets and its boom are seen over the right-hand half of the dredge. The gold separating apparatus is raised to the left of the boilers. The tailings elevator is raised projecting from the stern of the dredge beneath the crane.

buckets or of a revolving belt, which raises the waste material and drops it behind the dredge in a heap on the shore. Another form is the Payne-Peck elevator, a centrifugal machine that spits out the waste material and throws it on to the bank. The advantage of this contrivance is that it obviates the need of so heavy and expensive a dredge as is required to balance a large elevator.

The use of dredges is not confined to the actual river courses for which they were at first designed; they mine alluvial flats and flood plains beside rivers with equal success. A pit is dug and flooded, and the dredge floated in it. The dredge not only hauls up the material on the floor of the pit, but tears away the sides; it gnaws its way through an alluvial plain, filling up its track behind it with the waste material.

The second type of dredge, the suction dredge, works by a centrifugal pump instead of by buckets. It is really a gravel pump, which pumps up gravel instead of water. It may be used in places where the bucket dredge will not work; thus on a hard, rocky river bottom the gold may rest in crevices, from which the bucket dredge could not collect it, unless the bed rock has been shattered by blasting, so that the rock can be raised by the buckets. A suction dredge, however, can suck the bed rock clean. Suction dredges are mainly of value for use on alluvial flats, where the bed rock is hard and irregular. In such positions the dredge rests on the ground; a hole is dug before it down to bed rock; the adjacent gravel is washed into this hole by jets of water as in hydraulic sluicing; the gravel is sucked up by the pump and discharged over the gold-saving tables or down a long tail race, When the ground has been worked from the front of the dredge the hole is filled with water; the dredge is floated into a new position and the process repeated as before.

Dredging can be applied to any gold-bearing deposits which lie in comparatively level sheets either beneath or beside a river or upon a sea beach. Much of the success of gold dredging is due to the certainty with which the ground can be sampled, and provided the prospecting work is properly done and a dredge is selected suitable to the local conditions, this type of gold-mining appears to be unusually free from financial risk. The method of prospecting must vary with the local conditions; on a wide alluvial flat from one to four drill-holes in every ten acres may be sufficient. The gravel or sand is raised by a suction-pump from the bottom of the drill hole, and the gold carefully panned from the wash.

Gold dredges are successful because of the marvellous economy with which they handle great quantities of material. Some suction dredges which I once visited at Yackandandah, in Victoria, were earning a profit from ground that had been worked over four times by whites, and abandoned as useless by Chinese. Under favourable conditions a dredge will haul a cubic yard of earth from a river bed, sort it, wash it, and extract its gold for twopence, and sometimes even for less. The Vaughan bucket dredge at Castlemaine, during 1905, worked at a cost of 1½d. per cubic yard, and paid dividends by working deposits which yielded only ·96 grain of gold per cubic yard. According to Verschoyle, there are cases in New Zealand in which the work has been done for under one penny a cubic yard, or three farthings a ton. Hence dredges may earn a handsome profit with a recovery of two grains, or fourpence worth of gold out of every cubic yard of gravel. The average yield of all the bucket dredges in Victoria in 1905, was 2·04 grains, or four pennyworth of gold per cubic yard, or three pennyworth per ton. The Victorian suction dredges in the same year recovered an average of 3·12 grains.

### Deep Leads.

Gold dredging is an invention that has enriched most gold-mining countries. Another system of alluvial mining is of more limited application, but it happens to be of especial interest at the present time. It is the working of the deep leads of Australia. A deep lead, according to the Mines Act of Victoria, 1898, is, "any watercourse or gutter below the surface of the earth, containing alluvial deposits at a depth of not less than 100 feet from such surface."

The Australian mining industry began in 1851, and its first great success was the discovery of the rich alluvial gravels of Golden Point, Ballarat, on 24th August, 1851. The gravels there were exceptionally rich: for their gold had come from very rich lodes, and it had been twice concentrated by river action. The fame of the field was increased by the discovery of its gold nuggets, or masses of almost solid gold lying in the alluvial beds. The largest known nugget, the Welcome Stranger, which contained 190 lbs. of gold, was found at Moliagul; but the second largest, the Welcome Nugget, was found at

Ballarat in 1858; it weighed 184 lbs. 9 oz. 16 dwt., and was sold for £10,000. These sensational nuggets, even more than the richness of the gravel in bulk, made Ballarat the most attractive of the early Victorian goldfields.

Some of the deposits first worked at Ballarat lay on the beds of existing streams; but the richest material, including the gravel of Golden Point, was in old river beds known as "leads." The miners followed these leads, till their work was stopped against a cliff of the igneous rock, which formed the plateau of Ballarat West. It was feared that this igneous rock had completely destroyed the lower courses of the old rivers. This rock wall repelled the army of miners who were camped on the plain beneath as successfully as the walls of Sebastopol were then resisting the allied armies in the Crimea. Hence the plateau received its name of Sebastopol.

It was predicted by a Mr. Thomson, one of the staff of the Port Philip Mining Company, that the leads would be found to continue under the plateau of igneous rock; but the miners would not believe it, and insisted that the leads must pass southward along the face of the plateau down the present valley of the Yarrowee Creek. No traces, however, of the old river, in this direction could be found.

At length, in August, 1854, some miners at the White Flat Rush, at Creswick, a goldfield ten miles north of Ballarat, who were faced by the same difficulty, drove a tunnel straight at the face of the basalt. They discovered that instead of the rock being a thick, deep-seated mass like a granite, it was only a thin, superficial sheet like a lava, and beneath this rock the gravels were continued and safely preserved. This enterprise began the system of deep lead mining.

When the news reached Ballarat, the miners renewed the attack on their Sebastopol; they mined beneath its wall, traced the Frenchman's Lead beyond it, and thus began the mining of the buried gravels of Ballarat West. As they worked away from the edge of the plateau, they found it more convenient to reach their work by digging a shaft down through the basalt to avoid the great length of tunnel that would otherwise be necessary. The first shaft was put down in October, 1855. In the following year (June, 1856), the miners tried to economise work, by prospecting ahead of the actual mining. For this purpose they began the first of the innumerable boreholes which have been put down to discover the course of the buried leads.

Deep lead mining was comparatively easy where first developed at Creswick and Ballarat, for the general course of the lead was followed inward from its outcrop, and the water in the deposits could be removed without undue difficulty. The success of deep alluvial mining at Ballarat led men to consider the possibility of discovering leads beneath the other basalt plains of Victoria.

Large tracts of the State of Victoria are occupied by plains, and deeply buried beneath them is an old land surface with its valleys, river channels, and hills. In northern Victoria the plains are formed chiefly by the thick wide-spread silts of the Murray basin; in southern Victoria the most important plains are due to sheets of basalt which have flowed from numerous volcanic vents. At Ballarat the basalt has smothered the old divide between the rivers that formerly flowed directly southward into the Southern Ocean, and those that were tributaries to the Murray. The basalt plateau of Ballarat projects in long narrow bands, which extend for 50 miles to the north. These lava bands stand up above the general level of the country as plateaus, while the existing rivers flow through young valleys cut into the soft rocks on the edges of the lava.

The idea occurred to some members of the staff of the Geological Survey of Victoria that these lava plateaus represented ancient river valleys, that had been filled by basalt. After the close of the volcanic eruptions, the rivers were forced to cut new channels along the edges of the lava flows; hence in time the banks of the old valleys were worn down, while the floors of the valleys have been left upraised owing to the resistance of the hard basalts that filled them. This theory offered the only reasonable explanation of the distribution of these lava bands; and, if it were true, the old river beds, with their gold-bearing gravels, must still lie buried beneath the lava flows. The discovery at White Flat Rush in 1854 proved that the rich shallow leads of the Creswick Goldfield passed beneath the edge of the basalt sheet that flooded the old valley of the Loddon.

Krause's map of the Creswick Goldfield, published by the Geological Survey of Victoria in 1870, showed that the former course of the Loddon could be fixed between fairly narrow limits. The site of the old river banks is marked by the outcrop of the slates and sandstones on either side. The first practical suggestion for the search for the old leads was

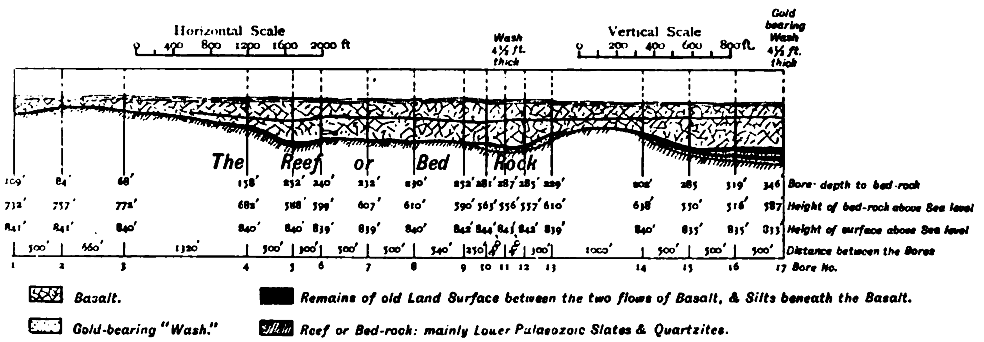
made in a report by Mr. R. Murray, then the acting Government geologist for Victoria. He reported (30th September, 1878) that from the geological survey of the country to the north of Creswick,

"It appears beyond a doubt that two main deep lead systems, fed by tributaries, pass eastward of Clunes, and unite to the north-east, between Eglinton Swamp and Glengower. The eastern of these two systems embraces the rich leads now being worked northward from Creswick and Kingston, probably fed by others, among which may be the extension of the Rocky lead. Of the western system little or nothing is known. Its existence is indicated by the basalt covering the country between the schistose rocks exposed at Clunes and those which form the western wall of the Creswick leads."*

its depth and width and the thickness of its gravels. The material brought up from the bores also shows whether the drifts contain gold, but the samples collected from the bores are so disturbed that they may not give reliable evidence as to the gold-value of the drifts.

The bores also give useful evidence as to the nature of the rocks beneath the lead. For coarse gold usually travels so short a distance that a lead is not likely to be rich at a point far from a source of gold. Where the old river crossed and recrossed a belt of gold-bearing lodes its gravels may be expected to be rich; but if it be crossing rocks that contain no gold, then the lead will doubtless be poor.

FIG. 5.




SECTION SHOWING RESULTS OF 17 BORES in the Parish of Moolort, on the basalt plateau of the Loddon Valley, made to discover the buried leads. (Reduced from the Section by Stanley Hunter: 1898.

Murray pointed out in his map the outlet through which the old river must have passed, and he proposed to put down a bore half way across this gap to discover approximately the probable depth and position of the lead.

This prediction has been amply justified by the results. The leads have been discovered and mined both in their upper reaches near the margin of the lava sheet, and lower down their course far out into the basalt plains.

In mining part of a deep lead it is first necessary to determine its exact position and depth. There is no indication on the surface of the site of the old river channel; the ground may be a bare level plain which is quite independent of the undulations of the former land. A line of bores is put down through the basalts and underlying drifts to the bed rock, and from the bore records a section is drawn showing the contours of the buried land surface. (Fig. 5). This section shows the position of the river channel or "gutter," as well as

By numerous lines of costly borings, most of which have been made by the Government of Victoria, the distribution of many of the deep leads of that State has been determined. The old valleys have been discovered buried beneath the silts of the Murray at Chiltern and Rutherglen, and under the basalts of the Loddon valley, the Ballarat plateau, and other districts of Victoria. The Loddon leads are the longest and the greatest; and as the rivers there crossed a belt containing many gold-bearing lodes, their gravels are often rich in gold. The position of the leads has been determined in so many places, that the general course of the old Loddon River and its chief tributaries has been discovered; and it can be represented on a map like an ordinary superficial river (Fig. 6); but it must be remembered that this river is sometimes buried under 500 feet of lava.

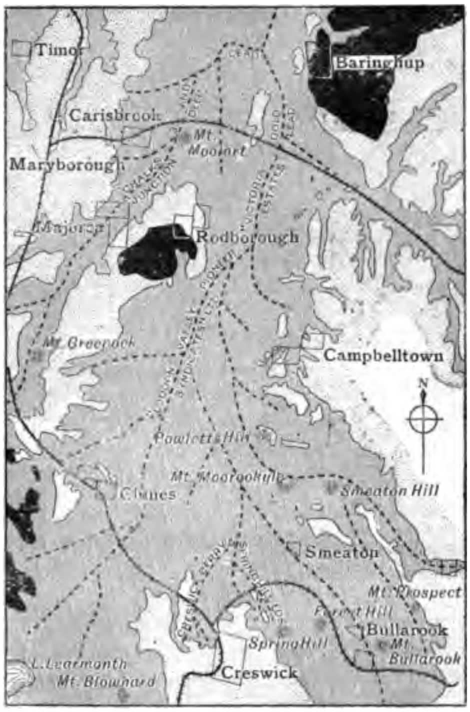
The course of the leads having been determined, the engineer proceeds to drain them. This is often a long and costly business; for the beds are water-logged, and their own water has to be removed; and while this water

* Progress Report Geol. Surv. Vict., No. VI., 1880, p. 48.

C

is being pumped out of the lead more flows in. It may come from two sources—rain water which runs in from the sides, and deep-seated plutonic water, which is recognisable by its higher temperature. The pumping plant has, therefore, to lift all this incoming water before it begins its main work of reducing the old accumulations in the drifts.

FIG. 6.




Reference.

*Granite* *Ordovician* *Basalt*

*Leads* *Railways*

Scale, 1 : 570,000

5 0 5 10 Miles

SKETCH MAP OF THE DEEP LEADS BENEATH THE BASALT PLATEAUS OF THE LODDON VALLEY, VICTORIA. (After Stanley Hunter.)

Mines have pumped a million gallons a day for seven years before being able to mine any of their gold-bearing material. The Great Southern Company at Rutherglen pumped two million gallons a day for five years. During recent years the necessity of having such powerful pumps that the accumulation of water can be rapidly dealt with, has been recognised ; for if a lead can be drained in one year instead of seven, the pumping of the six years inflow is saved ; and if the pumps can only keep pace with the incoming water the mine might go on pumping for ever. Quick pumping is, therefore, economical ; and acting on this principle the Loddon Valley Goldfields has erected a pumping plant capable of lifting 6,000,000 gallons of water a day ; and that mine and its neighbour, the Victorian Deep Leads, pumped in January, 1906, no less than 250,000,000 gallons of water in one month.

When once the gravels have been drained they are so easily and cheaply worked, that they often give returns which well repay the cost of pumping. The Madame Berry Mine, at the head of the Berry Lead, on a called-up capital of £15,000, raised no less than £1,588,515 of gold ; and paid over £900,000 in dividends and royalty.

There are two chief methods of deep-lead mining ; the method selected depends largely on the hardness of the rocks that have buried the lead.

In both systems the first operation is to put down a shaft. A site is chosen, if possible, where the solid bed-rock is exposed at the surface or it is known that the shaft will go at once from basalt into bed-rock without the risk of passing through quicksands. Where, however, shafts have the misfortune to encounter soft water-logged beds, the difficulties may be overcome by making the loose ground solid by freezing it until the shaft has been made and lined.

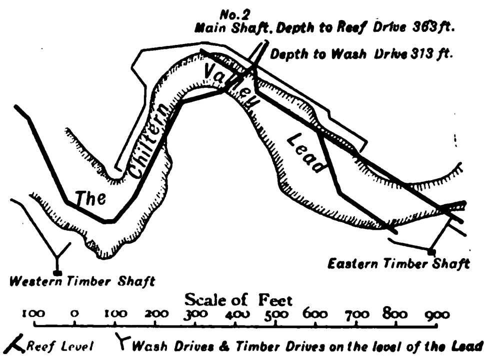
The main shaft is carried down into the bed-rock to a depth well below the deepest point on the lead. A drive is then made from a point a little above the bottom of the shaft through the bed-rock, or "reef" ; this drive is therefore known as the "reef drive." It is carried under the lead, and bores—3-inch pipes—are then pushed up from it into the gold-bearing beds ; their water rushes through the bore-holes into the drive, and flows along it to the pump chamber at the foot of the shaft. The number of bores opened is determined by the capacity of the pumps. As soon as the ground is sufficiently drained a rise is put up from the reef drive into the lead. The gravel, known as the "wash," is then dug out, and dropped down shoots into the reef drive, where it is run to the main shaft and hauled to the surface.

In the second plan of working a deep lead mine, drives are made from the shaft at two levels ; the lower one—the "reef drive"—is the main permanent drive of the mine, and is used for hauling and ventilation. (Fig. 7). The upper drive runs up at once into the wash, and is known as the "wash drive" ; it helps to drain

the lead in its neighbourhood, and from it cross drives are made to the edge of the lead; from the end of each cross-drive, a lateral drive is pushed forward along the edge of the lead. The ground is therefore blocked out by three longitudinal drives in the wash; the wash is dug out and dropped into trucks on the reef drive, which follows behind the work in the wash, thus avoiding the waste of unnecessary branches of the expensive reef drive.

In calculating working costs in these lead-mines, the unit is not the ton but the square fathom; for most of the gold is in the bottom of the wash, and as much gold may be got from wash three feet thick as from wash six feet thick.

FIG. 7.




PLAN OF PART OF THE CHILTERN VALLEY GOLD MINE, in the Chiltern Goldfield, Victoria. (Reduced from a Survey by Stanley Hunter.)

The extraction of the gold is done by simple puddling. The process consists of washing the material, sorting out the cleaned boulders and stones, and then collecting the gold from the fine sediment by the use of blankets, riffles, or mercury. As the mines are situated on level plains where there is no natural fall, the puddling machinery is erected on platforms high above the mouth of the shaft. The material then falls through the gold-separating apparatus by its own weight, and the waste can be run on to dumps across a raised tramway. A deep lead mine can be recognised from a distance by its high poppet legs, and by the huge piles of washed quartz boulders and pebbles extracted from the wash.

## SCOPE OF ALLUVIAL MINING AND CHOICE OF METHOD.

Some years ago the idea was prevalent that alluvial mining had done its work, and that it would soon be numbered among the extinct industries; for although new finds, such as those which have been made at Klondyke, in Siberia and South America might start fresh local centres, the room for such discoveries was being rapidly narrowed. But the combined work of the engineer and the geologist has given fresh impulse to alluvial mining. The field of its operations is steadily growing with the increasing capacity of modern mining methods. The three main systems of alluvial mining are each suitable to special areas. Deep lead mining is the most restricted geographically, and is at present confined to Australia; but it will no doubt be found applicable in some African localities.

Hydraulic sluicing requires an abundant water supply, a good fall, and thick gold-bearing deposits. So it is suited to mountainous country with an ample rainfall, where gold-bearing beds occur on the sides of deep valleys; and it can be most economically applied to deposits from 150 to 2(0 feet in thickness. If the beds are thinner, then much time is lost in continually extending the pipes and the sluices to reach the fresh ground. If the beds are thicker the face falls away in dangerous and unmanageable masses, and the mine may have to be worked in two benches.

Dredging offers the widest possibilities, for it may be applied to any level sheets of gold-bearing alluvium. It may be used on any sea beaches, river beds and riverine plains where the alluvium is not too deep for the tailings elevator to lift the refuse on to the bank. The use of dredges has spread from Australasia to North America, Siberia, Servia, Burmah and West Africa, and they have been tried in South Africa. We need not accept the confident prediction that the dredges will make so great a contribution to the gold yield of the world that they will have a revolutionary political influence, by raising the prices of all other commodities and thus lowering the price of gold. But the supply of low grade material which the dredges can work is so vast and so widespread that they promise to extend indefinitely the life of alluvial mining: all the gold-producing countries of the world are, or probably will be, indebted to the ingenuity of the New Zealand miners who have shown us how to collect gold from these low grade deposits, in which it would otherwise have lain beyond our reach.

## *LECTURE II.—DELIVERED FEBRUARY 4, 1907.*

### II.—GOLD-BEARING LODES.

The ideal of mining being the extraction of ores and minerals at the minimum of cost, mining operations should be guided by the best available evidence as to the underground courses of the ore deposits, in order to avoid the waste of search in wrong directions; and the miner should use the best available clues as to the depth to which a lode is likely to extend and as to its variations in value with depth, so that the mining equipment selected may be economically suitable to the work it will have to do. Hence comes the practical value of theoretical questions as to the geological characters and genesis of ores.

Alluvial gold is detrital in origin: at one time the belief was popular that the gold grains and nuggets in gravels grew there from percolating solutions. This view has a strange fascination over practical alluvial miners; and it is still occasionally advocated in mining literature.

Alluvial gold is derived from the destruction of gold-bearing lodes, and when the alluvial deposits of a field are exhausted the miner turns his attention to the lodes from which the detrital gold was derived. The work changes from alluvial to lode mining; and the gold in lodes is so constantly associated with quartz, that all gold lode-mining is sometimes spoken of as quartz-mining. Gold is, however, found, though usually only as a subsidiary constituent, in ores of silver, copper, lead and zinc.

### THE TERM "REEF" AND ITS OPPOSITE MEANINGS.

The quartz sheets in which gold occurs are called lodes, reefs, or veins. In accordance with the practice of Australia and South Africa, the generally adopted British term is reef; but that word must be used with caution, for it is used in different mining fields with exactly opposite meanings. On one field, the "reef" is the gold-bearing ore; on an adjacent field the reef, on the contrary, is the barren rock in which the ore deposits are included.

The responsibility for this confusion rests with Australia. During the first half of the last century, sheets of metalliferous ores were known as veins or lodes. Thus the Cornish mines derived their ores from the Standard Lode, Daniell's Lode, &c. From Cornwall, the term lode was introduced into America, and thus the great gold-quartz veins of the Sierra Nevada received their name of the "Mother Lode" of California, and the most famous ore deposit of Nevada is known as the Comstock Lode, not the Comstock Reef. The term reef was introduced into mining in Australia. The miners there began work on the alluvial deposits, and excavated them down to the underlying bed rock; then, in accordance with a habit of using nautical terms acquired in the long voyage to Australia, the miners said they had struck a reef; for striking the bed rock was as fatal to their mine as striking a submerged reef at sea would have been to their emigrant ship. So the bed rock was called the reef, a perfectly correct use of the term. When mining proceeded to the gold-quartz veins, they were described as reef-quartz, to distinguish them from the quartz pebbles of the alluvial deposits. From speaking of the quartz as "in the reef," the passage was easy to calling the veins "quartz-reefs," and thus the term reef passed from meaning barren material into a synonym for a lode. The term is still used in its original meaning in alluvial mining. Thus, the "reef drive" of a deep lead mine is the drive in the underlying, barren bed rock. It is probably too late to get rid of the double use of the word reef, and it is, therefore, important to remember that the term is ambiguous owing to its local reversal of meaning. The older name, lode, is not open to this objection.

### CLASSIFICATION OF GOLD-BEARING LODES.

Gold is found in lodes of many different types. The most typical gold-bearing lodes consist of sheets or masses of quartz, traversing barren rocks, which are technically named the "country." The lodes often occur in slates, which are readily worn away, so that the harder, more resistant quartz may stand above the surface in long, narrow walls.

Quartz mining in Australia was begun by a party of French miners chipping out the pieces of quartz showing visible gold from such an outcrop at Black Hill, Ballarat, and then crushing the fragments with hammers. After the outstanding part of a lode has been removed, the lode is followed down and quarried

by an open-cut. The rest of the lode, which is too deep for open working, has to be reached by a shaft and underground mining.

A lode may have parallel, well-defined sides, and such lodes are often of great length and depth. But, unfortunately for the quartz miner, even a thick lode may break up into thin quartz veins running irregularly through the country rock; or it may taper out and cease altogether. Vein quartz also occurs in lenticular masses, known as "makes," "bulges," or "blows"; so that what appears to be a thick quartz sheet may be only a part of a lens-shaped block, which, when followed downwards, soon becomes thinner and disappears. A thick quartz mass may be reduced to a mere string of quartz; it too may disappear, leaving only a narrow empty "lode track" which may, however, lead to another mass of quartz.

A lode may be formed by the filling of a fissure caused by the shrinkage of the rocks, or by a fault. The fissure may open above to the surface, and may be continuous across several rocks; or it may be a crack confined to one bed of rock, in which case it is called a gash vein. The quartz may occupy the whole width of the lode; or it may be deposited in the spaces between broken fragments of the adjacent rocks which have fallen into the fissure, or been torn off the walls. Some quartz lodes have sharply defined margins, but in others there is a gradual passage from the lode to the older rocks beside it; and these lodes are sometimes so thick, and occur at depths where the pressure is so great, that large fissures could not have remained open; moreover, projecting tongues or loose blocks of slate occur floating in the quartz in positions they could never have retained in an open space. Such lodes cannot, therefore, have been formed in fissures; many geologists were accordingly persuaded that quartz veins are of igneous origin; the quartz was thought to have been forced up from below in a molten state, to have pushed the rocks apart, and at the same time been injected into any adjacent cracks. Quartz veins were thus regarded as intrusive quartz dykes. This theory is, doubtless, true for a few quartz veins. There are igneous quartz dykes which are due to all the basic constituents in a molten rock having crystallized out, leaving the acid material to flow on as molten silica. They are the ultra-acid residues from ordinary quartz-felspar dykes. But I have seen no case in which quartz of igneous origin is payably auriferous. The economically important gold quartz lodes have had quite a different origin from such quartz dykes. The thick lodes are due to the slow replacement of slate or sandstone, particle by particle, by quartz. This process forms thick sheets of quartz, without the necessity for the existence of open spaces. Such lodes are described as metasomatic or replacement lodes, and more and more of the chief quartz lodes are being recognised as of this origin.

Quartz veins vary not only in mode of origin but in form, and in their relations to the surrounding rocks. The veins may run down as pipes in "pipe veins," as continuous sheets in "fissure veins," as a network of quartz enclosing broken masses of mullock along faults, or as irregular ramifications through a belt of shattered country between two powerful faults, or in numerous veinlets in the fractures beside faults, or as successive horizontal platforms or steps, or as "bedded veins" parallel to the bedding in the surrounding rocks.

The most useful classification of gold lodes rests on the nature of the rock in which they occur. The chief groups of lodes, arranged according to their character, are as follows:—

(1). Gold-quartz lodes in sedimentary rocks.

(2). Gold-quartz lodes in foliated igneous rocks.

(3). Mineralised belts of rock traversed by quartz-veins and veinlets.

(4.) Quartz lodes in association with propylitic igneous rocks, especially diorites.

(5). Gold-quartz lodes in non-schistose volcanic rocks.

(6). Gold occurring as a by-product in masses of pyrites or other sulphides, with their overlying rich secondary gossans.

(7). Gold-quartz ores formed by infiltration of gold into sediments, especially limestones and dolomites.

(8). "Banket," *i.e.*, ancient auriferous conglomerates, according to some authorities, should also be included among lodes.

### (1).—Gold-quartz Lodes in Sedimentary Rocks.

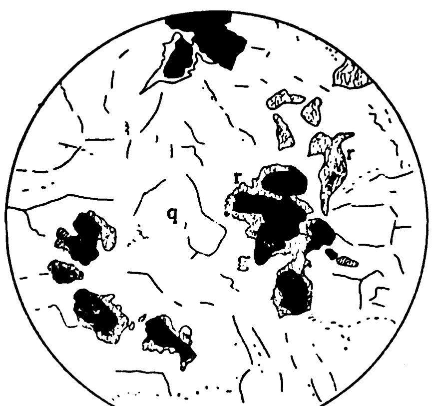
Of these various classes of gold ores, the most typical are the gold-quartz lodes and veins found in sedimentary rocks. They are, as a rule, found in slates, but they also occur in quartzites and limestones. The quartz is of the variety known as vein-quartz, which has been deposited from water. The lodes may consist of a sheet or pipe of quartz, of an irregular net-work of quartz-veins, of isolated lens-shaped masses, or of series of quartz

veins ramifying through a belt of mineralised country.

The simplest type of these gold-quartz lodes are simple fissure veins. Fissure veins often divide into many branches which are connected by cross veins, and thus form a complex lode. Many important lodes are found along faults, and contain broken fragments of the country rock; they are often called "brecciated lodes," from the abundance of angular masses of mullock included in them.

Where the country beside the lode is much fractured, the vein-quartz may not be limited by sharply defined boundaries, and there is a

FIG. 8.




A THIN SECTION OF GOLD-QUARTZ ORE WITH FREE GOLD. Sumpter, Oregon (after Lindgren) × 28 dia, $q$ = quartz, $g$ = gold, $r$ = roscoelite.

gradual passage from the quartz into slate beside it. The slate has been silicified, its original constituents having been removed and replaced by silica, till at length part of the rock is converted into ordinary vein-quartz. It is often impossible to draw a line between a simple fissure-vein formed along a fault or a joint and a replacement lode; and some lodes were first formed as fissure-veins, and have been enlarged by the replacement of the rock on the walls.

Lodes along faults have a tendency to develop into alternate masses or lenticles of quartz connected by a thin lode-track. The masses fill the spaces formed where the two walls of the fault are forced apart owing to the meeting of projecting surfaces.

Bedded veins, on the other hand, are often remarkably regular, as they follow the bedding planes. Where the rocks have been folded into alternate arches and troughs, the quartz may be deposited in thick bands along the tops of the arches and in the bottoms of the troughs, as the pressure in those positions was less than on the sides of the folds. Thus have been formed saddle lodes and inverted saddle lodes.

The most famous representative of all the lodes in sedimentary rocks is the great "Mother Lode of California." It is not one continuous vein, but a belt of many parallel and branching veins, which increase and decrease in thickness, and disappear and reappear on the same line. This complex lode can be traced for 112 miles north and south along the Sierra Nevada. It occurs in slates and sandstones of Carboniferous and Mesozoic age, which have been penetrated by great masses of igneous rock, known as granodiorite. The fracturing of the earth's crust and heating of the area during the invasion of these igneous rocks rendered possible the ascent of the gold-bearing solutions.

The gold-quartz lodes of Victoria include many examples of this group, most of them are in Ordovician slates, and many of them were formed before the Carboniferous period, so that they are much older than the lodes of California. The slates in Victoria have also been invaded by granodiorites and allied igneous rocks. Many of the chief gold lodes occur in the neighbourhood of these intrusive masses.

The great gold-quartz lodes of Ballarat West are typical examples of continuous sheet-like lodes, and the mines have followed shoots of gold ore down to the depth of 2,300 feet. The adjacent mines of Ballarat East, on the other hand, work lodes formed as an irregular network of quartz-veins ramifying irregularly through slates and sandstones. Saddle lodes are best developed in the Bendigo Goldfield in Victoria, and near Halifax in Nova Scotia.

### (2.)—GOLD-QUARTZ LODES IN FOLIATED IGNEOUS ROCKS.

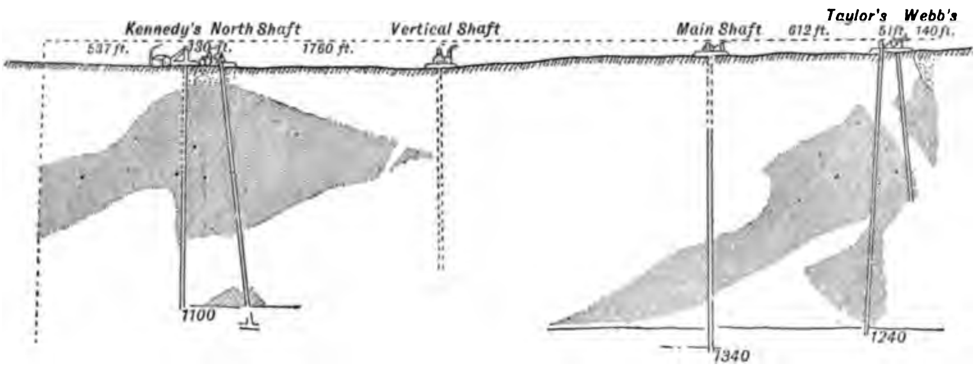
Gold-quartz lodes in igneous rocks which have been altered into schists are usually less regular than those in sedimentary rocks. The lodes are very variable in thickness, while their walls are often extremely irregular and indefinite. This is a natural consequence of the fact that igneous rocks, owing to their more complex chemical composition and higher proportion of soluble constituents, are less stable than sedimentary rocks, which are composed of simpler and less changeable materials. Hence most of the lodes found in

schistose igneous rocks are in the main replacement lodes.

Schistose igneous rocks, however, often preserve a more uniform composition in depth than sedimentary rocks, and it is, therefore, not surprising that the lodes and ore shoots in them often continue to great depths.

nated with auriferous sulphides are of great importance from their vast size, although the ores are usually of low grade. The lodes often occur in granite, using that name in its popular sense. Sometimes the quartz veins are so thin and pass so imperceptibly into the quartz grains of the country rock, that they are easily over-

FIG. 9.




LONGITUDINAL SECTION THROUGH THE NUNDYDROOG GOLD MINE, showing the dip and form of the Ore-Shoots. (After Hatch.)

Goldfields on schistose igneous rocks may be illustrated by Kalgoorlie with its famous Golden Mile. The lodes have been formed by replacement. They are generally in altered amphibolites, but sometimes the mineralisation passes outward into the granitic rocks beside the schists. The Kalgoorlie ores are very complex and refractory, and the absence of water placed great difficulties in the development of this field. But water is now pumped to it from the coast, through a pipe 350 miles long, and the ingenuity of the Australian miners has overcome the metallurgical obstacles to the extraction of their gold. The lodes have been followed down to the depth of over 2,000 feet, where the ores, though poorer than near the surface, still maintain rich values.

A simpler type of lodes belonging to this group is developed in Mysore in India, for the hornblende schists of the Kolar Goldfield, according to Holland's description, are altered igneous rocks. The shoots have been followed with well maintained values, down to the depth of 3,000 feet. The gold mines in the Selukwe and Sebakwe districs of Rhodesia occur in a field of which the structure in many respects resembles that of Mysore.

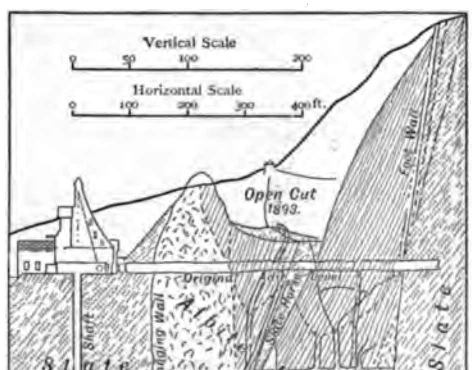
### (3).—MINERALISED GOLD-BEARING BELTS.

**Lodes which consist of mineralised belts of rock seamed with gold-quartz veins or impreg-**

looked, and thus the gold has been described as a primary constituent of the granite.

The simplest of these lodes are dykes of a variety of granite known as beresite, found at

FIG. 10.




SECTION ACROSS THE ALASKA TREADWELL MINE. (After Becker.)

Beresov in the Urals. Representatives of this group of greater economic importance are worked in many parts of the world in granitic rocks, such as the Alaska Treadwell Mine, on Douglas Island, off the coast of Alaska. Its ore is a mineralised "granite" or albite-

diorite; it is of low grade, containing gold to the value of 10s. 10d. to the ton, but the quantity is enormous; the mine is worked for a length of 3,500 feet, and the ore is crushed by a mill of 540 stamps. Owing to the large scale of the operations, and the use of water-power, the ore is treated for a total cost of 5s. 4d. per ton. The Jumbo Mine in Rhodesia represents another of these low-grade broad bands of "granite" impregnated with gold-bearing sulphides.

A second series of mines in mineralised belts of rock includes those in quartz-schists and quartzites. The most famous of them is the Homestake Mine in South Dakota, at present the greatest gold mine in the world. The country rock is a wide band of quartzite, seamed in all directions with gold-quartz veins. The lode has been mined for a width of 550 feet; the ore is crushed in three mills having a total of 1,000 stamps, and its gold is recovered by simple cyanidation. The Wanderer Mine in Rhodesia is another low grade mine with similar geological characters. It is a mineralised band of iron-bearing schistose quartzite.

The future of the gold mines of this group depends upon whether the gold will be confined within narrower limits in the deeper levels of the lodes. If the ore keeps of the same width and low grade as near the surface, the limit of profitable mining will be comparatively shallow, although the Homestake Mine has already a shaft down to the depth of 1,400 feet.

### (4).—Lodes connected with Propylitic Diorites.

The next important group of gold-quartz lodes are those associated with various dykes of igneous rock, and especially with diorite. This name is, however, given to many rocks which would not be accepted as diorite by a particular petrographer; but most of them are allied in chemical composition to true diorite, though, owing to differences in the conditions of their consolidation, they may differ in their mineral composition and structure. Many of the so-called diorites are hornblende-porphyrites, while many of the massive representatives are called granodiorites, being intermediate in composition between granite and diorite.

The lodes of this group are intimately and usually directly associated with the adjacent diorite. The lode and the diorite dyke may be in close contact, or, perhaps, occasionally separated by a block of the country rock. This type may be illustrated by the Long Tunnel and the Long Tunnel Extended Mines at Walhalla in Victoria. There the chief lode—the Cohen Lode—has been worked in more or less constant company with a diorite dyke to the depth of 3,100 feet.

In other mining fields the lodes are confined within the diorite; they then often consist of horizontal layers or floors of quartz, arranged like the rungs of a ladder. The dyke itself may be nearly vertical, while the quartz floors extend across it horizontally. Such "ladder lodes" are due to the igneous rock having cracked by contraction as it cooled; silica dissolved from the adjacent rocks was deposited as vein-quartz in the contraction spaces. Where the diorite happens to be firmly attached to the slates beside it, the fissures caused by the shrinking of the dyke extend into the slates; and in such cases, the quartz veins extend beyond the dyke, to which, as a rule, they are confined.

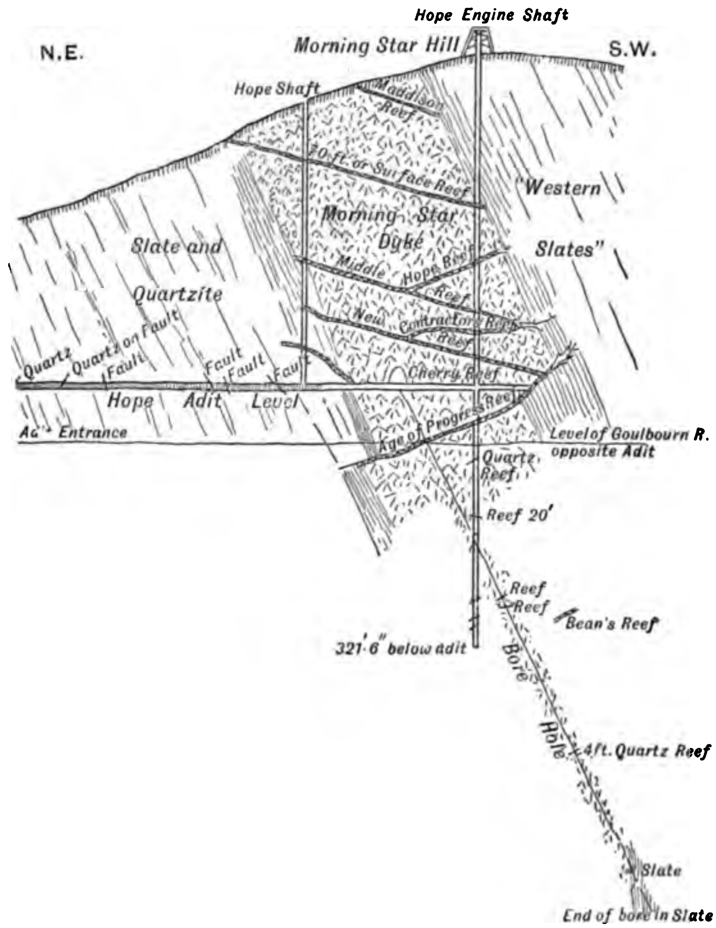
In most gold-fields where the lodes are in contact with diorite dykes, there has been lively controversy as to whether the dykes determine the amount of gold in the adjacent lodes. Very contradictory evidence has been adduced, which is, however, explained by the microscopic study of the rocks. Where the dyke is unaltered it appears to have had no effect upon the gold contents of the lode. But where the diorite has undergone the change known as propylitization, the adjacent rocks are auriferous. This change consists in the alteration of the original constituents of the diorite; the felspars have been changed into a secondary mosaic of quartz, felspar, and zoisite; the hornblende or other ferro-magnesian mineral has been converted into grains of epidote and chlorite. This propylitic action is a secondary process, which happened after the intrusion of the igneous rock, and usually affected both the diorite and the adjacent sediments. It is to this secondary action, and not to the diorite itself that the gold is due. The propylitic change can be certainly determined only under the microscope, but when its action has been thus detected, the change can usually be recognised in hand specimens of the rock. Among well-known mines in propylitic diorites are the gold mines of Chemnitz in Hungary, the famous Comstock Lode in Nevada, the Ayrshire diorite dyke in Rhodesia, and the A1 Mine at Gaffney's Creek, Victoria.

## (5).—Gold Lodes in Normal Volcanic Rocks.

Gold ores in association with non-schistose volcanic rocks are of great importance in various parts of the world, and some of them have been formed in comparatively recent times. These volcanic rocks differ from the schistose igneous rocks as they are younger, and have not been crushed into schists; and they differ from "diorite" as they are essentially volcanic rocks, which have been discharged in lava flows over the earth's surface, instead of being subterranean intrusions. The gold mines of this group may be illustrated by three chief types.

Cripple Creek, in Colorado, at present the richest gold-producing locality in America, is perhaps the most interesting. It is the stump of an old volcano, and is situated in the Rocky Mountains, a few miles to the west of Pike's Peak. Its ores are arranged in shoots and chimneys rising through the old volcanic neck. That hot vapours due to volcanic action were present during the introduction of the ores is indicated by the abundance of fluorspar in the lodes. The ores are more complex than those of ordinary gold-quartz lodes, and, as some of the gold is present as telluride, the ores require complex metallurgical treatment. The San Juan Goldfield in south-western Colorado contains vertical lodes traversing a thick series of volcanic rocks and breccias. The ores contain abundant tellurides, as we are reminded by the fact that one of the mining towns in this field is named Telluride.

Fig. 11.




Section Across a Ladder-Lode. The Morning Star Dyke, Wood's Point, Victoria. (After a survey by O. A. L. Whitelaw, 1905.)

Waihi, the chief gold mine of New Zealand, is situated in a wide volcanic plateau, and is also assigned to this group, but it has some resemblances to the mines associated with the propylitic diorites.

(6).—GOLD IN SULPHIDE ORE MASSES.

Gold as a subsidiary constituent is present in many masses of pyrites and lead ores. In these cases the mines are worked for their copper and lead, the gold being recovered as a by-product. As a representative of this group may be cited the Mount Lyell Mine in Western Tasmania, which was first opened as a gold mine, but subsequently developed as a low-grade copper mine. To a variety of this group belongs one of the most interesting and most discussed gold mines in the world—the Mount Morgan Mine in Queensland. It consisted in its upper workings of a siliceous ore showing such clear evidence of deposition from solution that it was originally described as a geyser deposit. The gold in the uppermost part or gossan of the lode had been deposited from solution, and its separation from other metals had been so thorough, that Mount Morgan gold still holds the record amongst the mines of the world for the purity or "fineness" of its gold. Some of it contained as much as 997 parts of pure gold in 1,000 parts of native gold. It is now generally understood that the cap of this remarkable mine is only the altered siliceous gossan of a great mass of pyritic ore, which is now being worked. The Mount Morgan Mine after being famous for the exceptional richness of its gold ores, has begun a fresh period of usefulness as a low grade copper mine.

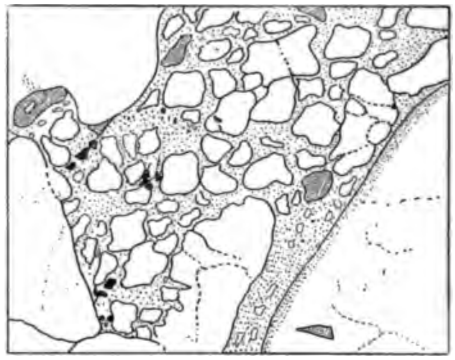
(7).—GOLD IMPREGNATIONS IN SEDIMENTARY ROCKS.

Gold ores due to the infiltration of gold into sedimentary rocks are formed mainly in quartzites, limestones, and dolomites. The solutions have usually risen up faults or beside dykes, and have then spread horizontally along a bed of permeable rock. One of the best established cases is that of the siliceous gold ores of South Dakota, near the Homestake Mine; the gold solutions have come up along the edges of dykes, and long vertical cracks known as "verticals." The ore bodies thus produced are compact and well defined.

(8).—BANKET.

Ores due to the infiltration of solutions into sedimentary rocks are comparatively unimportant, unless, as is asserted by a prevalent view, the gold of the Rand banket is of this origin. The ores of the Rand goldfield consist of beds of conglomerate or pebble reef, known as banket; this rock is charged with pyrites, and is often rich in very fine gold. (Fig. 12.) The banket or pebble-

FIG. 12.



BANKET. SECTION OF SPECIMEN OF THE MAIN REEF LEADER, containing 1,383 dwt. of gold per ton, × 25 dia. The section includes part of one large pebble of quartz and of two smaller pebbles; the rest consists of a fine quartz grit. The interspaces between the quartz grains are occupied by a dusty material composed mainly of minute flakes of sericite and kaolin, with small crystals of chloritoid. The large shaded areas are pyrites; the grains in solid black are gold.

reef was at first regarded as an old marine shingle beach, in which the gold was of alluvial origin. Evidence was soon forthcoming to show that this was not a full explanation; and it was suggested that the gold had been precipitated from solution in sea water, and then mechanically concentrated in the coarse conglomerates. This view is now only of historic interest. The theory which has been most generally accepted in recent years is that the gold has been introduced in solution and deposited in the conglomerate as in an ordinary gold-quartz lode.

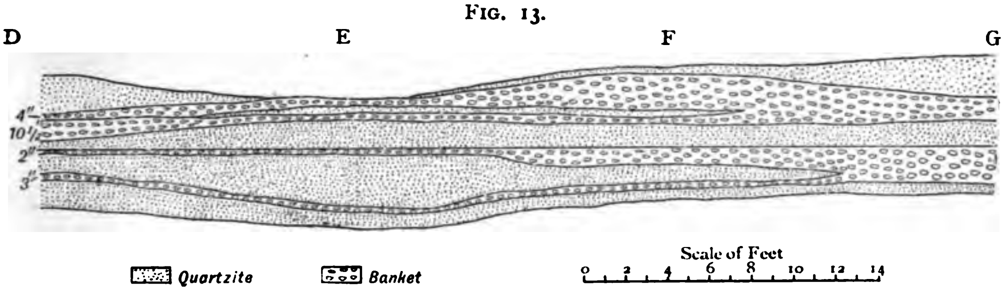
There is no time to go into this question, which I hope to treat shortly elsewhere; but the differences between the ores of the Rand and ore of which the gold has unquestionably been introduced in solution, and the many striking resemblances between the distribution of the gold with that of placer deposits, lead me to agree with the authorities who hold that the pebble-reef is an old placer, in which the gold was of alluvial origin, but has been dissolved and redeposited *in situ*.

### The Microscope in Mining Geology.

The characters of the different types of gold ores may best be recognised under the microscope. The use of the microscope in mining geology is of the highest value, and to it we owe the great progress which has been made during the last few years in the explanation of the genesis of ores. The evidence thus obtained, as to the origin of the ores gives, moreover, most illuminating clues to their distribution. Chemical analysis often detects no difference between ores of fundamentally different natures. A siliceous bedded ore and the vein quartz of a vertical gold-quartz lode may have identically the same composition. The chemist could recognise nothing in a specimen from the former inconsistent with its having come from a lode, which might carry its ore shoots down to vast depths. The microscope, however, would at once show that, though such a rock may be entirely composed of silica, it may have been formed by the silicification of a bed of dolomite; and any prudent miner would be prepared to find that the ore was either limited to that bed or completely changed its character if the lode passed into another rock.

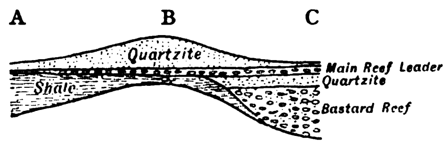
The microscope, moreover, can be of invaluable assistance to the mining engineer in detecting salting. Most of the commonest and most successful tricks of the salter can be detected by the study of the samples under the microscope.

Fig. 13.




Section along 45 feet of the South Reef in the New Goch Mine, Johannesburg, showing that the banket occurs irregularly interbedded with layers of quartzite. At D the section includes 4 beds of banket, in descending order, 4 inches, 10½ inches, 2 inches, and 3 inches thick, and of value respectively of 25 dwt., 5 dwt., 2 dwt., and 16 dwt. At E the 4 beds of banket are in descending order 4 inches, 4 inches, 3 inches, and 2 inches thick, and their values respectively are 19 dwt., 0 dwt., 9 dwt., and 81 dwt. At F the 4 beds of banket are in descending order, 20 inches, 5 inches, 11 inches, and 3 inches thick, and their values respectively are 2·6 dwt., 1 dwt., 6 dwt., and 19 dwt. At G the banket is in two beds, of which the upper one is 12 inches thick, and contains 12 dwt., and the lower is 21 inches thick and contains 4·6 dwt. Scale 1 inch = 5 feet.

Fig. 14.




Section Along 20 Feet of the Main Reef Leader in the New Goch Mine. The Leader increases from 2 inches thick at A, where its value is 36 dwt. per ton, to 4 inches thick at C, where its value is 162 dwt. per ton; at B the value is 16 dwt per ton. At A the Leader lies between beds of quartz, etc., and shale; the shale thins out at the other end of the section, and is replaced by a bed of Bartard Reef which at C is 36 inches thick, and has the value of 1 dwt. per ton. The value of the whole stoping widths are A 5½ dwt., B 3·9 dwt., C 30 dwt. Scale 1 in. = 10 ft.

### Practical Value of Determination of Ore Genesis.

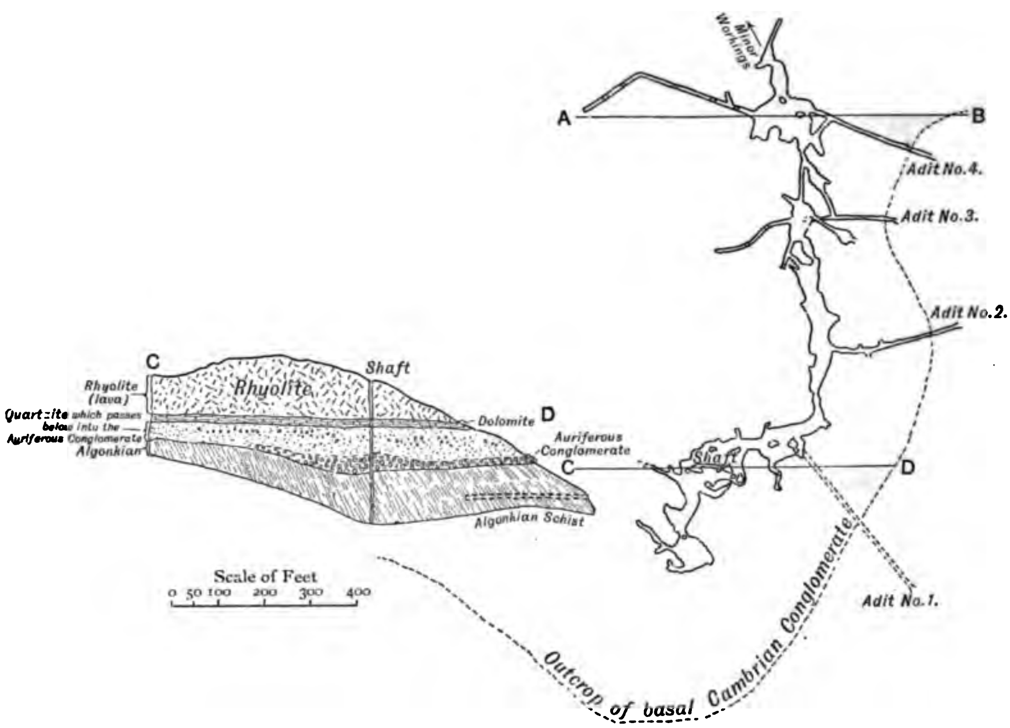
It is mainly from its bearing on ore genesis, however, that the microscope is an invaluable aid to the miner. It prevents him from being misled by those false analogies between different mines, which have been the cause of the disastrous failure of so many mining enterprises. The practical value of the determination of how an ore has been produced is now being generally recognised, and it may be illustrated by the following example.

At Bendigo the quartz veins were found in big "V" shaped masses, which rapidly thinned out below till they disappeared. The quartz was in isolated blocks which appeared to be distributed irregularly through the country rocks. The quartz blows exposed on the surface disappeared at slight depths; so it was thought that the field was practically worked out, all its lodes being shallow. The gold yield fell from 500,000 ozs. a year to only

similar positions recur one below another in vertical series.

Where a saddle reef is found, another saddle reef will probably occur below it, between some deeper layers of sandstone and slate. So the discovery of the lower saddles of quartz is not left to chance; their distribution instead of being capricious as had been feared, is quite regular; and when one saddle has been exhausted, a deeper reef may be found

FIG. 15.




PLAN AND CROSS SECTION OF THE HAWKEYE-PLUMA MINE, in the Gold-bearing Cambrian Conglomerate of S. Dakota. (After J. D. Irving.) The deposit is in an ancient river placer.

137,964 ozs. in 1890. It was noticed, however, that many of the quartz veins were parallel to the bedding of the slates and sandstones of which the goldfield is composed, and that neighbouring quartz veins sloped in opposite directions. The wedges of quartz were, in fact, only the tips of arch-shaped folds of quartz, each of which rested on an arch of slate, like a saddle on the back of a horse. So they were called saddle reefs. A saddle reef was often found between a band of sandstone and of slate, on the summit of an arch-like fold; and as the country consists of alternate layers of slate and sandstone folded together,

beneath it by sinking along the line of what is called "centre-country." Thanks to the guidance of this principle, the Bendigo Goldfield has had a new lease of life; it is the most prosperous of Victorian goldfields, and, instead of its mines being all quite shallow, they have been worked to the depth of 4,250 feet, and are the deepest mines in the world working gold-quartz lodes.

The neighbouring goldfield of Ballarat furnishes another illustration of the valuable guidance to practical mining given by recognition of the genesis of the ores.

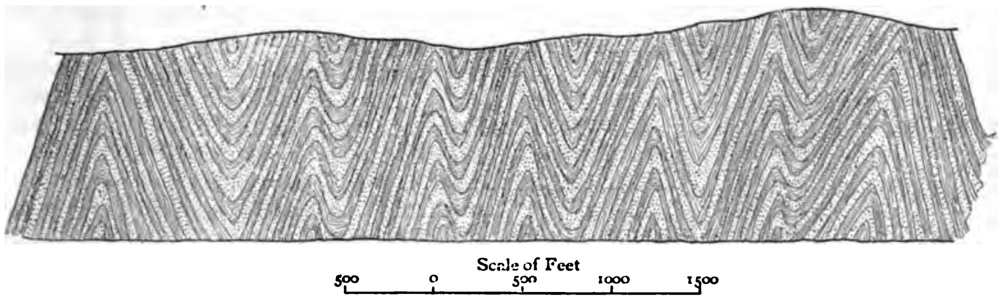
In Ballarat East, the hills are composed

mainly of slates, which are seamed in all directions by quartz veins; so irregular are they, that the miners declared that there were no true lodes in the goldfield—only a tangle of useless veins. The quartz in these veins was mostly barren, but the miners were tempted again and again to prospect them, as they had certainly yielded the great gold nuggets for which Ballarat is famous. The efforts as a whole were unsuccessful, but the miners were occasionally rewarded by the discovery of rich patches or nuggety masses of gold; the distribution of these rich patches appeared so capricious that it seemed useless to search for them. But at length the clue to their distribution was discovered. The slates are traversed by numerous secondary seams of chloritic minerals, produced along planes of what is known as slip-strain. (Fig. 18.) The chloritic minerals, when decomposed, give rise to materials which can precipitate gold from its solutions.

Where one of these seams meets a quartz vein, a rich patch of gold often occurs at the point of intersection, whereas a few inches away on either side the quartz is quite barren. The chloritic seam continues beyond the quartz vein, and at its intersection with the next quartz vein there may be another nuggety patch of gold. These narrow seams are found, in fact, to lead to the points where the gold is concentrated in the quartz veins. Hence, as they indicate where the rich gold was found, they are called indicators, and many of the mines of Ballarat East have been worked successfully by following these seams from one rich patch of ore to the next. The whole of the gold in the area is not found on these indicators, for much of it comes from veins and masses of quartz along faults. But in a critical period in its history, the field was saved by the discovery how to use these indicators in the search for the rich nuggety patches of gold.

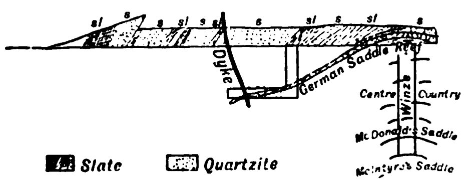
These instances show the necessity of the

Fig. 16.



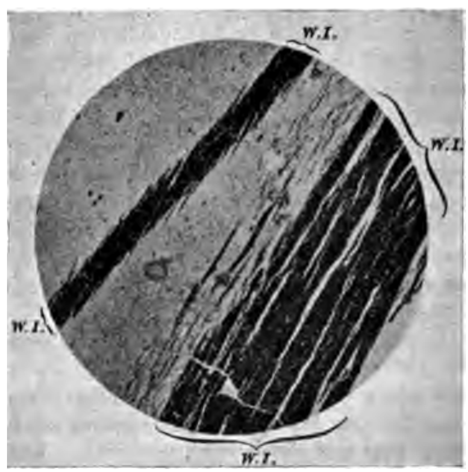

Section Across the Castlemaine Goldfield. Composed of contorted slates and quartzites, with which are associated bedded quartz veins developed as saddle reefs. (After W. Baragwanath, Jnr.)

Fig. 17.




A Saddle Reef in the Cartlemaine Goldfield. (After W. Baragwanath.)

Fig. 18.




A Microscopic Photograph of a thin Section of the Western Indicator of the Ballarat East Goldfield, enlarged 15 diameters. The indicator consists of thin lenticular patches of chlorite, formed along the planes of slip-strain cleavage.

detailed geological study of mining fields; for two of the most important goldfields in Victoria, of which one was thought to have only shallow ore-bodies, and the other to have no lodes at all, have been successfully developed since the discovery of the plan of their gold distribution. So long as it was believed that no better explanation of the distribution of the rich gold patches and quartz masses could be given than in the old Cornish mining proverb, "where they are, there they are," the continued success of those fields was impossible. But now that we know "why they are where they are," the Bendigo mines have been carried down till they hold the existing record in depth of gold-quartz mining.

## *Lecture III.—Delivered February 11, 1907.*

### III.—Gold Extraction, the Variations of Mines in Depth, and the Gold-mining Industry.

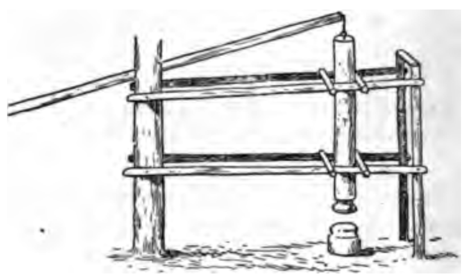
The fame of Rudolph Eric Raspe as the author of "The Surprising Adventures of Baron Munchausen" has eclipsed his former infamy as a mining adventurer. During his varied career Raspe found himself in Scotland, where he raised £30,000, with which to exploit some vast mines of mercury that he claimed to have discovered in the north-western Highlands. To promote his scheme and increase his own authority on the matter, he published in 1791 an English translation of Baron Inigo Born's valuable work, "The New Process of Amalgamation of Gold and Silver Ores;" for Raspe maintained this process would lead to an immense demand for mercury, as with it, gold could be obtained from rocks which had hitherto yielded none. Any Scotch mercury mines that there may be, are however still unworked; for Raspe and the £30,000 passed silently away to other fields of activity.

The use of mercury for collecting alluvial gold is very ancient, as it is mentioned by Pliny; but it was apparently not until 1566, that it was found that the process of amalgamation would extract gold and silver from other ores. This discovery, made in Mexico by a Spaniard, Fernandez de Velasco, opened a new epoch in the history of gold-mining; for it supplied an economical method of extracting gold from ores, whence it could not be recovered by washing.

#### The Stamp Battery.

The ancient method of working gold-quartz ores was to break the quartz into coarse fragments and then grind it to powder between a hard stone and a flat surface of rock, like an ancient corn mill. The underlying rock is worn away, forming a groove, in which the broken quartz can be mixed with water and thus washed while it is being ground. Such simple hand quartz mills may be seen beside some of the old mines in Rhodesia, and the grinding stones, balls of a tough diorite, are found beside them. This simple hand mill is the most primitive form of quartz crushing machine. The second device was probably some kind of pestle and mortar, which, in the form of the hand dolly, a strong iron pestle and mortar, is still used in prospecting and sampling. The passage thence was easy to a pestle work by a lever, such as is still used by the Chinese in the Northern Territory of South Australia.

Fig. 19.



A Primitive Stamp. Still used by the Chinese Miners in the Northern Territory of South Australia. (After Basedow.)

Gradual increase in the size and complexity of the mechanism led in time to the German mill, which was developed in Germany at the beginning of the sixteenth century in order to crush the ores of the Erzgebirge and the Harz Mountains. It is illustrated in the excellent figures in Agricola's "De Re Metallica,"

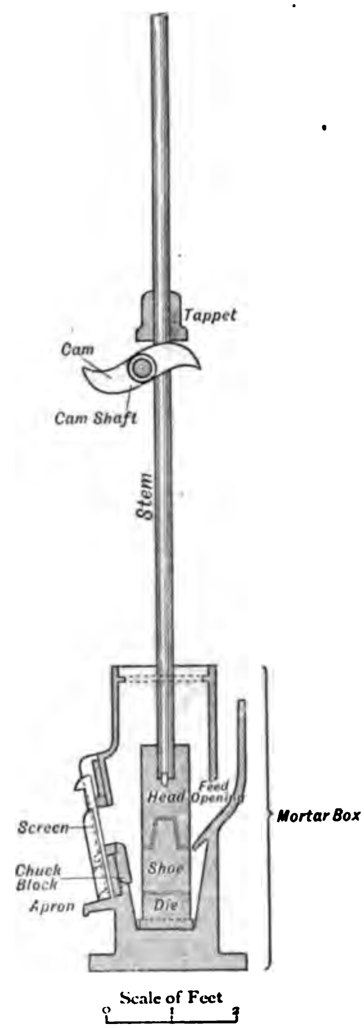
published at Basle in 1556. The German battery may still be seen and heard in this country in the Cornish tin mines. It consists of a broad flat-footed pestle, called a shoe; the pestle is lifted by a projection on a revolving shaft, and falls by its own weight upon fragments of ore. At first the ore was pounded upon an open floor and was crushed dry, but the advantages of enclosing it in a box and washing it at the same time were obvious, and Agricola's book shows also an improved battery provided with a mortar-box. These batteries were worked by men or horses, but generally by water power. The German battery remained the best thing in quartz-crushing machinery until it was taken in hand by the miners of California, who improved it into the modern stamp battery. The Californian battery differs from the German by having circular pestles or stamps, which are rotated while being raised so that the striking face of the stamp is worn evenly. The stamps are lifted by cams fixed on a revolving shaft, they fall on to dies in the mortar-box, and the ore is smashed between the stamps and the dies. (Fig. 20).

The stamps are usually grouped in sets of five, each set in one mortar-box; the sets are arranged in series, each of which, in large mills, usually includes fifty stamps. The greatest number in any one mine is at the Homestake in South Dakota, which has a mill of 1,000 stamps, and even larger mills are proposed on the Rand.

The ore may be fed into the mortar by hand or automatically; the finely crushed ore or "pulp" is splashed about in the mortar-box, where it comes in contact with the mercury usually kept there. This mercury catches some of the gold, and more is caught on the "chuck block" in front of the screen, through which the pulp escapes from the mortar. This "inside amalgamation" is, however, not always used. How much of the gold it is wise to collect in the mortar-box depends on many factors which are not all mechanical. One important consideration may be the theft of amalgam if left exposed on the plates. On the Rand this loss has been described as a severe tax on the mining industry. At Mysore it is found advisable to crush the ore extremely fine, in order to collect most of the gold inside the mortar-box, where it is less exposed to thieves.

All branches of mill management have been discussed in great detail. The best order in which the stamps should fall, for example, has quite a literature of its own: and there is no doubt the efficiency of the battery can be greatly increased by a suitable order of the fall of its stamps. There has also been prolonged discussion and experiment as to the best arrangement of the screens. They are used of different heights, and there has been much controversy as to whether it is

FIG. 20.




CROSS SECTION (Scale ½ inch to 1 foot) THROUGH A STAMP AND MORTAR-BOX.

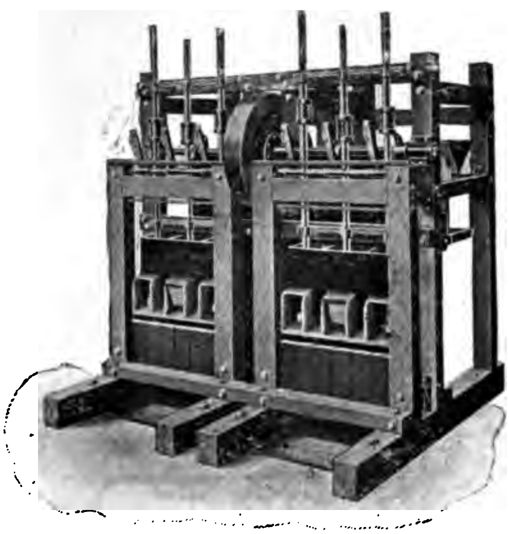
better to have the screens vertical, as is usual in Australia, or to have the upper side inclined outward, the usual American practice, which is adopted also in Mysore and South Africa.

There are many types of stamp battery, which differ in very important respects. During recent years the stamps have been increased in weight from four hundredweight

to 1,500 lbs. At the same time, the number of blows struck per minute has been increased by reducing the fall of the stamps to from six to nine inches, and it is thus possible to give them a more rapid action, each stamp falling perhaps one hundred times a minute. The desire for still greater speed has led to more fundamental changes.

The more blows a stamp gives, the more ore it will crush in proportion to its weight; hence it is desirable for a small mine, to which transport is very costly, to drive its battery as quickly as possible. Accordingly the efficiency of the stamps has been increased by batteries in which the blow of the stamps is not due to gravity alone. In mills of the Tremain type, which have been used with success in Rhodesia and West Africa, the stamp is both lifted and driven down by steam; and thus a light two-stamp mill will do more work than a heavy five-stamp gravity battery.

FIG. 21.



MERRALL STAMP BATTERY.*

A quicker action can also be obtained, as in the Morison battery used at the Meyer and Charlton Mine, Johannesburg, by working the stamps by cranks, whereby 1,600 lbs. heads are driven at the rate of 130 blows a minute, and crush quartz at the rate of ten tons a day.

A second line of reform raises the crushing power of the battery by increasing the rate of discharge from the mortar; this can be done by enlarging the area of the screens through which the pulp escapes. One method is to have screens on both the front and back of the mortar-box; but this reform has not found general favour, though it has been used at many Australian mines with good results. The extreme development reached on this line is the Merrall Mill. (Fig. 21.) In that machine each stamp works in a separate mortar-box, which has a screen on each of its four sides; hence the discharge is naturally much quicker than when the material is discharged only through one front screen.

Another and still more revolutionary change in ore crushing is following from the need for the very fine crushing usually necessary for cyanidation. This reform may, therefore, be considered after reference to the methods of gold extraction from the crushed ore.

## GOLD EXTRACTION.

The processes of gold extraction may be divided into four main groups—amalgamation, smelting, chlorination, and cyanidation.

Amalgamation depends on the power of mercury to combine with gold to form an amalgam. The process is applicable to ores carrying free gold, even though it may be completely enclosed in pyrites; as it then usually occurs free in cracks or cleavage planes in the pyrites, and thus can be recovered, if the ore be ground sufficiently fine for the mercury to come in contact with the gold.

Amalgamation may be begun in the mortar-box; the rest takes place on sloping copper plates, rubbed with mercury, which are situated in front of the battery.

Battery amalgamation cannot recover all the gold. The gold contained in fragments of pyrites, "amorphous" gold, gold that has been over hammered, and any covered with oil or slime, all escape amalgamation. Such gold and gold-bearing material has to be collected by some process of concentration into "concentrates." They may be obtained by washing the pulp from the battery down a long channel, and collecting the heavier material by riffles, or on the rough surface of strips of canvas or blankets on the floor of the channel; or the material may be sorted according to the specific gravity of the particles on revolving tables known as buddles; or on shaking tables (vanners and the Wilfley); or by "sizing" the materials by currents of water through such appliances as pointed boxes (Spitzkasten).

The concentrates thus obtained may be

* This block is kindly lent by the Sturtevant Engineering Company.

ground in Californian mills or Berdan pans, and then amalgamated. Some concentrates, however, do not yield their gold by amalgamation, and require more complex chemical treatment. The oldest method was smelting, and this may still be advisable for some refractory sulphides and tellurides, such as some of the ores at Cripple Creek and Kalgoorlie. Economic smelting requires a mixture of different types of ores, which are not usually found in the same mine or mining field; so it is conducted in special smelting centres, such as Denver—which collects the various ores of Colorado—and Swansea and Freiberg, in Saxony, which smelt ores received from world scattered mining fields.

Smelting is of less importance in dealing with gold ores than the chemical processes of chlorination and cyanidation.

The chlorination process is due to the work of Percy, in 1846, and of Plattner, in 1848. It is an application of the power of the gas chlorine to combine with gold forming auric chloride which is soluble, and can thus be leached out of the altered ores. The formula representing the process is :—

$$3\ Cl + Au = Au\ Cl_3.$$

The gold can be precipitated from the auric chloride solution by charcoal, iron, ferrous sulphate, &c. The process is applicable to many complex ores, and is used, for example, at Cripple Creek, and in dealing with pyritic concentrates in many fields; but it has been superseded to a great extent by the younger and simpler process of cyanidation, which has the advantage of not requiring the roasting of the ore.

*The Cyanide Process.*—The cyanide process is due to MacArthur of Glasgow. It depends on the fact that a weak solution of cyanide of potassium will disolve gold in the presence of oxygen as auro-cyanate of potassium.

$$Au_2 + 4\ K\ Cy + O + H_2\ O = \\ 2\ K\ Au\ Cy_2 + 2\ K\ HO.$$

The gold can be recovered from the solution by precipitation with zinc or electrically by the Siemens-Halske process. There are many variations in cyanide practice in accordance with the varying nature of the ores. Some American mines and the Great Boulder Proprietary Mine at Kalgoorlie use sodium cyanide instead of potassium cyanide. Bromocyanide is added to the vats as well as potassium cyanide in treating the telluride ores of Cripple Creek and some of the mines of Kalgoorlie (the Lake View Consols, Oroya Brownhill, and Kalgurli mines).

The cyanide process is very simple and economical. It is generally used after the coarse gold has been separated by amalgamation. The crushed material that is carried over the copper plates of the battery is called the tailings. If the mine is in a hilly country, the natural slope of the ground is used so that the tailings can be carried through the various tanks by gravity; but in a level country, such as the Rand, the tailings are lifted from the battery by a high tailings-wheel to a platform, which gives sufficient fall for a current of water to carry the material through the remaining stages of the separation.

The tailings consist of sand and of fine material of the consistency of mud, which is called slime.* The sand and slime are separated by two sets of separators, the "spitzlutten," and the pointed boxes or "spitzkasten"; from them the light slimes are carried off at the top and the heavy sands from the bottom. The heavy materials collected by the first separators are known as the "concentrates"; and they may be ground up and the gold extracted by mercury, or they may be treated by the chlorination process.

The rest of the sand passes into huge tanks, wherein it is allowed to soak for some days in a weak solution (usually ·1 per cent.) of cyanide; or it is stirred up with the cyanide in tanks by agitators. The gold is dissolved and the solution drawn off from the bottom of the tanks and passed to the extractor house.

The slimes are mixed with lime, which coagulates them, so that they settle while most of the water runs off clear. The settled slimes are then stirred up with cyanide, their gold is dissolved, and this solution also passes on to the extractor house. There the various cyanide solutions are run into extractor boxes, and the gold precipitated. Zinc is the usual precipitant, and the gold is collected from the precipitate by smelting in a furnace with a flux, such as one of borax, sand, and bicarbonate of soda, or of borax, sand, and manganese dioxide. An electric method of precipitation is sometimes used instead. The barren slimes from the cyanide tanks are allowed to run away if there be a natural fall, or they may, as at Kalgoorlie, be stacked by a tailings elevator, and ultimately used to fill up the excavations in the mine.

* Its particles are of a diameter of not more than ·0002 inch in diameter.

### Fine Crushing—The Tube Mill and Filter Press.

This invaluable cyanide process was at first used to supplement the other processes, but it has to a large extent supplanted them, and threatens to do so still more in the future. It had one difficulty from which at first there seemed no escape. Dilute cyanide is only an effective solvent for porous or very finely crushed ores; it therefore requires the fine crushing of the material subjected to it. But ore ground so finely that all its gold can be recovered by cyanide is as impermeable as mud. The resistance to the entrance of the solution can be overcome by stirring the slime and solution together in agitating tanks. But when the fluid has got in, the mud takes such a firm hold of it that the gold solution will not drain out. Out of this dilemma Australian mining led the way.

The first process was to improve the system of crushing the ore. The stamp battery is not a suitable instrument for the breaking up of big blocks of stone, for they are apt to tear and smash the screen. Again, the battery is not economical in very fine crushing; for, unless the supply of water, the power, and the size of screen be perfectly adjusted, the stamps waste their power in pounding fragments of quartz in a yielding mass of soft sand.

Accordingly, the battery wanted help on each side of it, so that it may be confined to the work for which it is most effective. The ore is therefore broken into fragments of suitable size by rock breakers. The ordinary type of crusher used for breaking rocks into road metal are employed for this purpose; the ore may be crushed between powerful jaws, or by a gyrating steel cone inside a massive steel funnel. The material can be passed through series of rock breakers, each breaking to a smaller size; and instead of this tandem arrangement there may be a compound crusher, such as that of the Sturtevant Engineering Company. The ore is thus reduced to the size most suitable for the battery to deal with it.

The use of rock breakers has long been adopted in many mining fields; but the relief of the stamp battery by the use of special fine grinding appliances has been more recent, and has been productive of more important consequences. The first step was to relieve the battery of the finer crushing. The mesh of the battery screens was enlarged so that the ore escapes as sand instead of as slime, and each stamp therefore crushes much more ore than it would otherwise do. The Waihi Mine, for example, increased the output of its batteries 30 per cent. by enlarging the mesh of the screens from 40 holes to the linear inch to only 20 holes. And according to Chester's experiments, when the Rand ore is crushed through a 10-mesh screen, each stamp will crush 9¼ tons a day; whereas the same battery with a 30-mesh screen crushes only 4·64 tons a day. The stamps of the miner, like the mills of God, grind slowly when they grind exceeding small.

The material that escapes from the mortar-box through these coarser screens passes over amalgamation plates which collect the larger particles of gold. The sands have then to be reduced into slime by some instrument better adapted for fine grinding than the battery. Various forms of accessory grinding machines have been employed, such as the Huntingdon mill, the grinding-pan, and the ball mill, but the most famous now is the tube-mill. This machine was developed in cement works to grind up soft limestones. The limestone is fed into a revolving cylinder, and churned up with hard flint pebbles which act as millstones, and grind the limestone to slime.

This machine, variously known as the tube-mill, the flint-mill, or the grit-mill, was introduced into gold mining at Kalgoorlie where it was well suited to the soft tough ores of that goldfield.

A diagram of the larger tube-mills used at the Lake View Consols Mine is given in Fig. 22. It consists of a revolving drum, 16½ feet long by 4 feet in diameter; it is lined with manganese steel plates one inch thick; they are used until they are worn down to a quarter or an eighth of an inch in thickness. The drum is half filled with a load of rounded flints weighing about 4½ tons; some 35 tons of sands are run into it. The mill is rotated at the rate of 29 revolutions per minute, and the flints grind the sand into fine slime. The mill is mounted on two hollow trunnions through which the ground material is carried away by a stream of water. The fine slime flows to the separating tanks, and the coarser material is returned to the mill. About 300 tons of ground ore pass through the mill in a day, and some of the material goes through it eight or ten times before being reduced to slime. The flints are gradually worn away. The tube-mill, illustrated by Fig. 22, consumes 1,000 lbs. of them a month. The flints may remain in the mills until they are completely destroyed; but it is sometimes the practice,

as at the Oroya-Brownhill Mine, to sift them periodically, and reject all those that will go through apertures of 1½ inches diameter, as they are found to contribute little to the grinding, while they use up power.

The slime from the tube-mill flows into tanks, where it is stirred up with cyanide solution by revolving agitators; the finest gold is therefore dissolved; but no process of natural draining will extract all the solution from the slime.

Recourse is therefore had to Dehne's filter-press. The slimes may be roughly drained, and placed in layers between sheets of cloth in a press, or they may be pumped into it by a plunger pump. Weak cyanide solution is forced through the press to dissolve any remaining gold, and then the solution is washed out of the slime by a current of fresh water driven through the press by a force pump

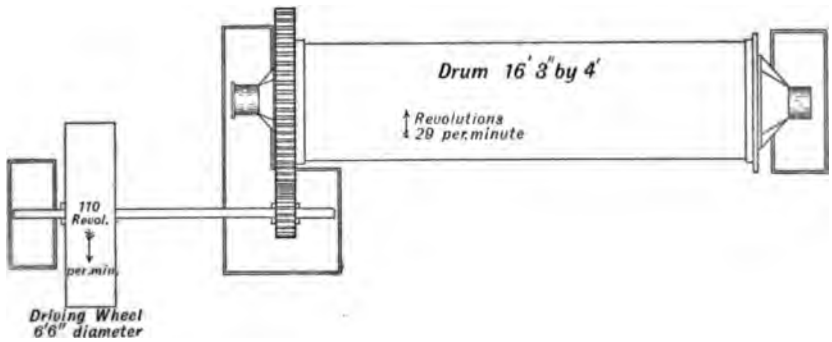
This combination of fine grinding and the filter press has given increased scope to the cyanide process, for it renders possible the almost complete extraction of the gold from slimes. South Africa has recently adopted tube mills with characteristic enthusiasm, and thereby gained increased profits by extracting gold which would otherwise have gone to waste. But meanwhile in Australia their use has been reduced on the ground that they are extravagant of power. They have been discarded at the Ivanhoe Mine for example, and grinding pans used in their stead. It is held by many Australian miners, and by Messrs. G. A. and H. S. Denny from their South African experience, that grinding pans do the same work as a tube-mill, and more cheaply. According to the results of one set of experiments, 30 horse-power applied to a grinding pan does as much work as 70 horse-power in a tube-mill. The Australian experiments have been severely criticised, but the miners who first realised the value of the tube-mill may probably be trusted to treat it fairly in their tests.

The policy for which the tube-mill was introduced is unquestionably sound, and will be continued; but it is possible that the tube-mill itself has not come to stay, and may be replaced by some more economical machine. The filter press also is being attacked in Kalgoorlie, and the Ridgway Atmospheric Slimes Filter is claimed to do its work as efficiently, while it is more convenient, as it acts continuously and automatically.

*Suggested Abolition of the Battery.*—The great development of cyanidation rendered possible by these reforms is threatening the abolition of amalgamation and even of the stamp battery. In some places the battery has been abandoned in order to save water. The battery is a very thirsty instrument; it uses on the Rand, according to Mr. G. A. Denny's estimate, ten tons of water to crush one ton of ore. The system of dry crushing reduces the consumption of water, and avoids the use of amalgamation. The ore is ground between rollers or in pans, and then passed at once to the cyanide tanks. This system was once employed at Waihi, in New Zealand, and may be seen in use at the Wanderer Mine in Rhodesia, where the broken oxidised ore is readily permeable, and the gold is extracted at a total cost for mining and milling of 6s. 9d. per ton.

The most advanced attack on the battery is that proposed by Messrs. G. A. and H. S. Denny, and to some extent adopted in the very original plant erected by them at the New Goch Mine, Johannesburg. The battery

FIG. 22.




PLAN OF A TUBE MILL as used at the Lake View Consols Mine, Kalgoorlie.

is fed with cyanide solution instead of water, and the ore is kept circulating in cyanide throughout its course through the separating plant. The gold is all dissolved during this circulation, and there is no need for huge cyanide tanks and special agitators. In the New Goch Mill the ore is broken to fragments in rock breakers, then crushed to sand in a stamp battery; next it was ground to slime in tube-mills, which have, however, been replaced by grinding pans. The gold solution is extracted from the slimes by filter presses.

The logical development of this system, with ts restriction of the work of the battery by rock-breakers on one side and all-sliming by fine grinders on the other, and the abandonment of amalgamation, is the abolition of the battery altogether. And this revolutionary proposal the Denny Bros. have already advocated. They recommend the crushing of the ore in a series of rock breakers; the reduction of all of it to slime in grinding pans; its continuous treatment by cyanide as it passes through these machines and from one to the other; and the treatment of the slime in filter presses.

Threatened institutions however live long; and it may be long before the resounding roar of the stamp battery ceases upon the goldfields, although that machine has already lost the monopoly of ore crushing which it so long enjoyed.

### Gold Yield of 1906.

The gold supply of the world is now unprecedented; and is apparently still growing. The total yield for 1906 is estimated at over £80,000,000 which is the highest on record, and twice as great as in 1896, and four times as great as in 1886, or only twenty years ago.

This great yield has been contributed by 46 countries, of which the three chief producers are the Transvaal with a yield of £24,579,987, the United States with a yield of £19,431,040, and Australia with a yield of £16,570,312. The Australian output, to which the State of Victoria has been contributing for 56 years, shows the baselessness of the old fear that gold mines are all necessarily shallow. Some ore shoots are certainly limited in depth; but others go down deeper than it will probably pay to follow them for years to come.

### Variations of Mines in Depth.

The future of any goldfield depends on the depth to which its ores will continue; opposite opinions have been freely expressed as to the *depth to* which gold ores may extend. Both views are locally correct. There may be two adjacent mines, in one of which the ore shoots may be shallow, in the other they may continue downward for thousands of feet. This difference is not a capricious accident, but is the result of definite ascertainable causes.

The once prevalent belief in the shallowness of gold deposits was largely the result of the unquestionable fact that, as a rule, gold veins become poorer and less profitable to work as they are followed deeper. The outcrop of a lode is the easiest and cheapest part of it to work for many reasons. The ore is decomposed and soft, and contains many cavities, so that it is easily mined; a block of it weighs less than an equal sized block of deeper ore; the gold is usually visible to the naked eye, and is very conspicuous in the rust-red ore. In the deeper levels, on the other hand, the ore is compact, hard, and heavy; the gold may be combined with the pyrites and so invisible and perhaps difficult of extraction; and below water level the working places have to be drained by pumping.

Hence the miner finds the deeper ore more troublesome and less profitable, and it has to be worked on a much larger scale than is possible to a party of working miners. The surface ore, moreover, is both absolutely and relatively richer, owing to the processes of surface and secondary enrichment. Surface enrichment is due to the rapid precipitation of gold from a gold-bearing solution when it approaches near the surface of the earth; for its temperature is then quickly reduced, and the oxygen and carbonic acid in the surface waters precipitate all the gold that has escaped deposition in deeper levels.

*Secondary Enrichment.* — This surface enrichment is aided by secondary enrichment. This process may be illustrated by reference to a quartz vein, in which gold is uniformly distributed. If the surface of the mining field be lowered by denudation, the gold in the top of the lode is dissolved by a solution formed by the action of the rain-water on the iron pyrites in the lode. The gold is carried a stage lower, where the iron sulphate is reduced and the gold and pyrites re-deposited. Hence the new top of the lode contains the metals originally distributed through twice the length. This concentration is repeated again and again, until a rich gold patch, such as the famous Londonderry pocket, may cap a comparatively worthless lode.

The richness of the gold quartz lodes at their outcrop led to the view that gold ores are

always shallow, a doctrine which received most authoritative expression from Murchison; and at one period in the history of gold-mining the incoming of the sulphides meant the abandonment of the mine.

### Mining Costs.

The deeper refractory ores can, however, now be treated, and the downward limit of mining is determined sometimes by the ending of the ore-shoot, and sometimes by the grade becoming too low to pay the increasing costs of mining. There is no simple universal rule which governs the depth of gold ores. The downward extension of each field must be judged independently, considering its geological structure, and the quantity of its ores.

In many fields the gold ores continue deeper than it is at present possible to follow them profitably. But the range of mining is being steadily enlarged, for though the difficulties increase as mines deepen, the costs may be reduced by working on a larger scale, and with improved machinery. The winding by hand or whim is replaced by a powerful engine; the shaft is enlarged, and instead of being kept vertical, may be inclined so as to keep close to the lode, and thus avoid the cost of long cross cuts through barren rock, and unnecessary underground haulage of the ore. Inclined shafts are used all along the Rand, whereas most American and Australian shafts, like the lodes they work, are vertical. Modern shafts and cheap haulage; machine drills, which in large operations are probably always more economical than hand labour; and the more perfect adjustment in processes of gold extraction have all contributed to the steady reduction of mining costs. The consideration of costs in different fields involves so many uncertain factors that it is not always easy to make fair comparisons. Thus in Victoria, for example, fields with the same conditions of wages and transport, and mining ore of the same hardness from similar country rocks, have costs varying from 13s. 11d. per ton of 2,240 lbs., at the North Noah Hawp Mine, which is doing mainly pocket mining, to 20s. 6d. at the South New Moon at Bendigo; one mine on the Bendigo Goldfield, the Central Ellesmere, from 9,480 tons, yielding $1\frac{1}{5}$th dwt., or 4s. 10d. per ton, did not quite pay its expenses, though a neighbouring mine secured a profit out of a yield of [illegible]s. 4d. per ton.

The range of mining costs may be illustrated by the following examples. In Mysore, the costs at the Mysore Mine are 32s. 1d. per ton of 2,240 lbs.; on the Rand, the average for 1904 was 30s. 8d. per ton of 2,000 lbs.; in Mexico, the costs of the El Oro Mine are 28s. 3d. per ton of 2,000 lbs.; Western Australia, in spite of its refractory ore and costly water, has costs of 18s. 5d. per ton of 2,000 lbs. at the Ivanhoe Mine, and 16s. at the Great Fingall.

Rhodesia, though hampered by long railways and its costly pioneer development, has creditably low costs; the average of six typical mines is 23s. 11d. per ton of 2,000 lbs., while individual large scale open-cut mines work more cheaply; the costs at the Wanderer Mine, for example, being about 6s. 9d. per ton of 2,000 lbs.

The United States shows such low costs as 10s. 3d. per short ton from the Homestake Mine of South Dakota, and in some of the gold-quartz lodes of California; the cheapest great American mine, the Alaska Treadwell, which crushes partly by the aid of water-power for 6d. a ton, has total costs of 5s. 8d. per ton of 2,000 lbs.

Still more remarkable is the record of the Stewarts United Mine in the Bendigo Goldfield where, according to the official returns of the Victorian Mines Department, a gold-quartz lode was mined, in 1905, at a profit, although the ore, of which 7,104 tons was raised in the year, yielded only $1\frac{1}{3}$ dwt., or 5s. 4d. of gold per long ton.

Every mine manager is, or should be, engaged in a never ending struggle with costs. He may win by inventing new processes of ore treatment, or by greater economy in management. But when all has been done in these directions it may still happen that the ore is too low in grade for profitable working. Most men who have visited mining fields must have been grieved by the pathetic position of a mining engineer striving against difficulties which rendered financial success at the time impossible. The only chance in many such cases is in the reduction of the cost of living and of wages, by changes in the general condition of the district. There may, for instance, be two mines containing ore of the same value and bulk: one may be a valuable property; in the other the ore may not be worth the price of road metal; for the one mine may be in a locality with good roads and a settled agricultural population, so that transport and food are cheap, and the conditions of life so comfortable that miners will accept comparatively low wages. The other

mine may be in uninhabited back country, with costly transport and no local food supply; hence wages must be high to satisfy the cost of living and compensate the miner for the risks of taking employment remote from other fields of industry. In such cases the wisest policy may be to delay the development of the mine until the economic conditions can be altered and there is a chance of working it with success. Its premature development involves the tearing out of the rich ore patches with a precarious chance of profit, and the low grade material must be left unworked, and is, perhaps, wasted for ever.

### Gold Mining as an Industry.

The credit of gold mining suffers from a reputation for reckless speculation, but the common view of its unprofitableness is exaggerated. It is sometimes said that the gold in the world costs more to produce than it is worth. In some young fields this statement is true, but it is ridiculous when applied to a State like Victoria, which has yielded £280,000,000 of gold in 56 years. It has been claimed, on the evidence of a census of the failures of gold mining companies, and of those engaged in ordinary industrial and agricultural work, that gold mining has lost a smaller proportion of the money subscribed for it than other industries. This result is intelligible, for gold mining is the one enterprise which has nothing to fear from the state of the market. The product is indestructible; its cost of transport is inappreciable; and there is no fear of a slump in price by over-production. The three great causes of failure in gold mining, are (1) over capitalisation; (2) rule of thumb procedure, leading to the choice of unsuitable methods; and (3) the frequent necessity for distant and therefore often expensive control.

The most sensational failures have been reckless extravagance due to over haste in the development of a field in consequence of a sudden boom. The history of Coolgardie with its wild waste of British capital in hopeless schemes is an example of this type of failure. Of the three causes of failure, the greatest is over-capitalisation, due to extravagant hopes, which are generally based on false analogies. This loss would be lessened if investors would estimate the value of a mining property for themselves, and trust for reward to dividends from the mine and not to profits from the share market. The estimation of the value of a mine involves three factors:—

1. A true appreciation of its g
structure, so that its future may be e
by the history of a really similar mine
2. An estimate of its probable lif
speculative, but may be a matter c
calculation. It is usually necessary to
separately ore already proved to e
that of which the existence is probl
but which may be reasonably exp
occur, and to be workable at a profit.
3. The cost of extraction, depe
local economic conditions, the qu
the ore available, and the readiness w
the gold can be extracted from it.

Gold mining may be organised on
different systems. It may be develo
local industry, or as an investment fc
capital. The method which has fou
favour in Eastern Australia, for ex
that of local development. A mine
covered by a prospector, who works i
or with a party of "mates" until th
exhausted the outcrop, and the depth
too great for their simple appliance
work, however, has shown the valu
upper part of the lode, and probab
mined the position and length of
shoot.

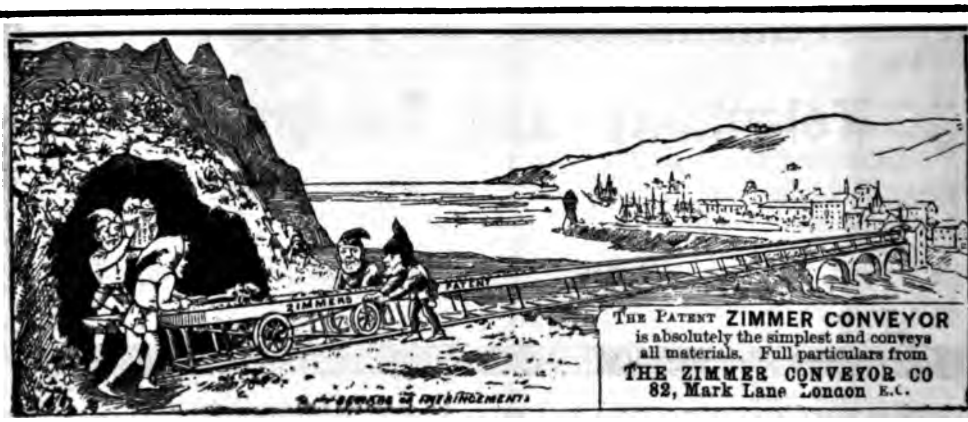
A few thousand pounds are raised
investors and spent in the erection of
battery and the construction of a sha
money, judiciously and economicall
probably raises sufficient gold to p
larger equipment and more extensive
ment. Thus the mine is made to
itself. The Mount Morgan Mine, for
produced its vast output without, acc
a recent speech by Sir Horace To
capital at all; and the Madame Be
won its million and a half of gold with
of £15,000. The great advantage
method is that no great sum of money i
while the future of the mine is uncert
there is no insatiable drain upon the
the mine to pay the interest on a huge
The drawbacks are that such mines
begun by men of limited experience,
be baffled when they meet new co
and if the mine strikes a zone o
ground, it has no reserve fund with
prospect for better ore, and has to m
upon the shareholders There is n
economic objection to the system of cal
merely assumes that shareholders are
of investing their capital more judicious
selves than a mining company can
them. It often happens, however, th

calls give a mine a bad name. The shareholders are discouraged, they refuse to subscribe, and the mine may be abandoned, when further prospecting would have given it a new lease of life.

The antithesis of this method of gold mining is that which has been found necessary in South Africa. The prospector finds some indications of a mine, pegs out a claim, and sells it to a syndicate. The syndicate founds a Developing Company to develop the mine. The Developing Company may build a branch railway to the locality, erect the necessary plant, sink shafts, drive levels, and prove the mine by elaborate and costly sampling. Years later, the Developing Company founds a Mining Company to mine the property thus opened up. All this time the capital has been growing steadily, and the mine starts work with a handicap, which, though a good property, it cannot bear. There are mines in South Africa, with only a five or ten stamp mill, which have to pay the interest on a capital of £100,000 or £200,000 before they begin to make a profit, and repay the money that has been spent on them. A ten stamp battery, unless supplemented by other grinding appliances, cannot be expected to crush more than 15,000 tons a year. If the mine have a capital of £150,000, it has an interest charge, at 5 per cent., of £7,500 a year, and must earn a profit of 10s. per ton of ore crushed to pay the interest alone. Only the profit earned in excess of this very creditable amount is available to refund the capital.

Both systems of mining have their critics and advocates. The East Australian method is especially condemned for the comparatively crude sampling which is possible with it. But both methods have their uses, and are right if applied where they suit the local opportunities. The present great output of gold is due to the adaptation of mining methods to the different needs of widely-scattered fields; and the industry as a whole is well-managed, in spite of the gambling in shares, which is parasitic on it. Its success is indispensable to modern industrial prosperity, and it has had a deep influence on economic theories. Thus, in Bryan's opening speech in the present electoral campaign in the United States, he explained that he had abandoned bimetallism, as that system was no longer advisable, owing to the unexpected increase in the world's gold supply. The great existing gold output may be regarded with the more satisfaction, as the success of one country is not gained at the expense of the rest. There is no underselling, and the progress of one mining field usually adds to the prosperity of others. All the chief mining countries have contributed to the methods of modern gold mining. Germany invented the stamp battery, which owes its present high efficiency to America. Percy, of London, gave us chlorination, and J. S. MacArthur, of Glasgow, the cyanide process. California devised hydraulic sluicing, and New Zealand the gold dredge; while Australia, besides leading the way in deep gold-quartz mining, developed the modern system of fine-crushing and filter-pressing. Every important advance helps gold miners throughout the world, for, to the honour of the industry, there is no attempt to keep gold mining processes as jealous secrets. Gold miners of all nations recognise that they are colleagues and not competitors, and share their successes together as an international, industrial brotherhood.

PRINTED BY WILLIAM TROUNCE, 10, GOUGH SQUARE, FLEET STREET, LONDON, E.C.



ZIMMERS
PATENT

---